Baseline Benthic Plastic Debris Assessment and Intertidal Survey in Iqaluit, Nunavut Canada for 2016 and 2017

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A Thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of

Master of Science

Department of Environmental Science

Memorial University

February, 2024

St. John's, Newfoundland and Labrador, Canada

Abstract

Marine plastic pollution is a global issue affecting food webs, humans, and the natural environment. There is limited marine plastic pollution research in Iqaluit and the Arctic in general. This thesis focuses on Iqaluit, Nunavut targeting intertidal and marine benthic debris in areas with high human activity such as fishing and hunting areas, shipping locations, and the proximity to the city. Data includes sampling from October 2017 as well as previously collected (2016) sediment grab samples and seafloor video collection. Benthic grab samples and seafloor video were examined for anthropogenic debris including microplastics (<5mm) and macroplastics (>5mm). An intertidal survey was conducted at low tide to determine the amount and types of land-derived plastic debris that may enter Frobisher Bay as a possible point source for marine plastic pollution. Determining the abundance of both microplastics and macroplastics will create a baseline for marine plastic pollution found in Frobisher Bay, NU. This thesis includes protocols for sampling in extreme environments and provides an analysis of methods that are replicable for monitoring benthic and terrestrial marine debris. No significant changes in benthic marine debris occurred during 2016 and 2017. The results indicate a baseline of 0.002 plastics/mL of benthic debris, 0.055 plastics/minute for benthic seafloor video, and 0.379 plastics/m^2 of shoreline debris for marine debris in the Frobisher Bay area and Iqaluit, Nunavut.

Acknowledgements

Thank you to my supervisor and mentor Dr. Max Liboiron, Department of Geography, Memorial University of Newfoundland for their support throughout this entire process.

Thank you to my advisor committee member and mentor, Dr. Evan Edinger, Department of Geography, Memorial University of Newfoundland and for the opportunity to fill an empty spot on the MV *Nuliajuk* in 2017 for sampling.

My appreciation to Daniel Martin, instructor at Nunavut Arctic College and the second year Environmental Technology Program students 2017 for inviting me into their class and participating as research students. I would like to thank Rick Martin at Nunavut Research Institute for coordinating my accommodations, public meetings, and workshop. I want to thank the Nuliajuk ship crew: Bob Bennet, Shawn Lynch, Des Jordan, Alf Burton, Evie Kilabuk, and Linda Kanayuk and to Robert Deering for his guidance and help in the field and report writing.

My thanks to Alex Zahara who helped edit and be a mentor. Thank-you to Laura Day to create the GIS maps. I extend thanks to Kaitlyn Hawkins for confirming samples in the lab as I worked remotely. Thanks to Erin Herder and Ben Misiuk for allowing me to use their research samples from previous years and the metadata that came with them and assisting with any questions. Gratitude to two WISE (Women in Science and Engineering) students, Mikayla Downey and Erin Burt for their benthic video analysis.

Financial support for this thesis through MEOPAR (Marine Environmental Observation, Prediction and Response Network), ArcticNet, and SSHRC through Dr.

Liboiron. Additionally, ArcticNet support was received through Dr. Edinger. In addition, the NSTP (Northern Scientific Training Program) award provided financial support for field work conducted in October 2017.

This thesis has been made possible by the support of my family, Susanne Bradshaw (mom), Brian Bradshaw (dad), Allison Sadowski (stepmother), Benjamin Bradshaw (brother), Lauren Bradshaw (sister-in-law), Madison Bradshaw (niece), and Olivia Bradshaw (niece) throughout this entire process. Many thanks to my friends near and far that supported me through this journey. A special thanks to my loving partner, Paul Forwell for believing in me. A special appreciation to all my animal friends. I am honoured to have worked with so many talented people and the opportunity to conduct research in the Canadian Arctic.

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Chapter 1: Introduction and Overview

1.1 Introduction

Marine plastic pollution is a global environmental catastrophe affecting the natural environment and impacting food webs. Microplastics have been found throughout the ocean globally including in surface waters, the water column, and the benthic environment (Classens et al., 2011; Eriksen et al., 2013; Kukulka et al., 2012; Nakki et al., 2012; Reisser et al., 2015; Setala et al., 2016; Van Cauwenberghe et al., 2013). Marine plastic pollution is defined by the United Nations as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (UNEP, 2009). Plastic pollution enters the natural environment through different pathways from land-based sources such as: human activity, open landfills/dumps in proximity to the coast, sewage and storm-water outflows, and human-made drainage (Corcoran et al., 2009; Galgani et al., 2011). It also enters through ocean-based sources such as: commercial and recreational fishing and shipping, offshore installations, and research vessels (Andrady, 2011; Galgani & Hanke & Maes., 2015: 31). Microplastics (MP) have been characterized in the marine pollution literature as 'primary' or 'secondary' debris, based on plastic type and sources. Primary plastics are pre-production pellets also known as nurdles, while secondary plastics are the result of the break-down of plastic debris through mechanical forces such as wind, waves, or photodegradation (Andrady, 2011; Bergman & Klages, 2012; Bergmann et al., 2017; Galgani et al., 2015;). MP can be distributed through the environment by wind, rivers, ocean currents, atmospheric deposition, and species dispersal (Wichmann et al., 2019;

Reisser et al., 2013; Masó et al., 2016). Microplastic debris may also be classified by size. Common size categories include microplastics (<5mm), mesoplastics (4.75-200mm), and macroplastics (>200mm) (Arthur & Baker, 2011; Eriksen et al., 2014). Plastic pollution has the potential to harm animals through entanglement, ingestion, and toxicological impact (Andrady, 2011; Cauwenberghe et al., 2013; Dekiff et al., 2014; Engler, 2012).

Plastic pollution has increased exponentially since the 1970s due to increases in plastic production. While marine plastic pollution (MPP) research has increased over the last two decades, research on plastic pollution in northern benthic environments has been limited. This is particularly true in areas of the Arctic, where studies are limited due to cost, accessibility, and sample collection challenges (Bergmann & Klages., 2012; Bergmann et al., 2017; Galgani et al., 2015). MPP has been found in large quantities in benthic environments all around the globe, however, in remote locations there is less debris found (Barnes et al., 2009; Galgani et al., 1995; Galgani et al., 2000). Most northern studies of MPP focus on ingestion, floating debris, trawl surveys, sediment coring, and beach surveys (Bergmann & Kalges, 2012; Bergmann et al., 2017; Kühn et al., 2018; Woodall et al., 2014), however benthic studies have been limited. Further research in northern contexts is important as plastic pollution has the potential to cause harm to benthic environments, organisms, and their associated food webs (Andrady, 2011; Engler, 2012; Masó et al., 2016).

1.2 Literature Review

1.2.1 Marine Plastics in North

Northern marine plastic debris is sourced from a number of combined environmental and human factors. Some studies have suggested that northern Canada may be affected by benthic marine plastics as a result of fishing industry and coastal communities, as well as increasing shipping and other industrial activity as sea ice recedes (Coe & Rogers., 1997; Mallory., 2008; Zarfl & Matthies., 2010). More recently, studies have suggested the northern regions, including those of Canada, may be a sink for plastic pollution caused by long-range transport via currents, atmospheric deposition, biotransport through migrating animals, and shipping debris (Bergmann et al., 2017; Bourdages et al., 2020; Claessens et al., 2011; Cózar et al., 2017; Huntington et al., 2020; Lusher et al., 2015; Obbard et al., 2014; Zarfl & Matthies., 2010). The majority of studies in northern Canada focus on ingestion studies for monitoring (Amélineau et al., 2016; Mallory., 2008; Provencher et al., 2010) and limited studies in water sampling (Lusher et al., 2015) and in Arctic ice (Obbard et al., 2014). There is very limited literature for benthic studies within shallow waters and deep sea sediments.

1.2.2 How Plastics Sink

As human activity moves further from land and deeper into the ocean, there are unknown anthropogenic impacts in benthic environments. Studies estimate that about 50% of plastics sink to the seafloor making the benthic environment an accumulation zone for plastics (Engler., 2012; Goldberg., 1997; Gregory et al., 2009; Williams et al., 1993). The vertical movement of marine plastics through the water column is a research gap in marine plastic literature, though trends are emerging. Plastics with different densities interact differently in the water column (Reisser et al., 2013; Thevenon et al., 2014; Woodall et al., 2014; Zarfl & Matthies., 2010). Plastics with a greater density than water can sink in both marine and freshwater environments (Corcoran et al., 2015). In addition to polymer type, added weight from the environment from biofouling can adhere to plastics and increase the density to cause faster sinking rates (Bergmann et al., 2017; Ye & Andrady, 1991), mineral absorption (Corcoran et al., 2015), adhering to fecal matter and sediment (Coppcok et al., 2017; Reisser et al., 2013; Thevenon et al., 2014). Marine plastics can experience yo-yoing, which is when submergence and resurfacing occurs until the debris finally sinks (Ye & Andrady., 1991).

1.2.3 Sources of marine benthic plastics

Marine plastics can be transported to the oceans through different pathways such as: wind, rivers, tides, rainwater, storm drains, sewage outfalls, wastewater, flooding, and landfills (Reisser et al., 2013; Rech et al., 2014; Sheavly., 2005; UNEP., 2005). Marine shipping also contributes to marine debris through traffic waste (Shaw & Mapes., 1979; Vauk & Schrey., 1987). Marine plastic will likely end up in the benthic environment regardless of polymer density due to the factors mentioned above (Galgani et al., 2015). Marine plastic research shows that plastic in the benthic zone is due to recreational, agricultural, and industrial activities from land and from vessels discharging at sea (Goldberg, 1997; Reisser et al., 2013). Fishing activity is one source of plastic pollution affecting the benthic zone due to lost or discarded fishing gear which can be potentially harmful to animals and the environment (Bergmann et al., 2015; Moore & Allen., 2000).

Wastewater is a potential source of benthic plastics. MP can enter the marine environment through inefficient wastewater treatment management (Browne et al., 2011). Sewage outfalls are known areas of discharge of MPs entering the benthic environment (Browne et al., 2010; Habib et al., 1998; Reed et al., 2018; Zhang et al., 2019). Road runoff can also be a potential source of plastics entering the marine environment. Another way microplastics get distributed vertically in the benthic environment is through bioturbation which is the process found in soft-bottom seafloor environments where the fauna alters the environment, changing the seafloor habitat (Kristensen et al., 2012; Näkki et al., 2017).

1.2.4 Distribution of Marine Benthic Plastics

Seafloor debris is found at all depths of the oceans (Gregory., 2009). Intertidal zones in proximity to highly populated cities are prone to higher concentrations of marine plastic pollution due to land source outputs (Mathalon & Hill., 2014). Benthic debris often concentrates around coastal cities and river mouths, however, the concentration of marine debris is also often greater in deep waters along the continental shelf edge than in shallow, inshore waters due to the decrease in bottom currents offshore (Barnes et al. 2009; Galgani et al. 1995; Galgani et al., 2000; Keller et al. 2010). Keller et al. (2010) found higher concentrations of plastic debris in deeper waters than in mid-depths and shallow waters.

Concentrations of seafloor marine debris are dependent on geomorphology, currents, and human activity. Coastal areas have higher concentrations of benthic debris from the outfalls, river mouths, and ocean circulations (Consoli et al., 2018; Wei et al., 2012). Rocky and overhang areas of the benthic environment have higher concentrations of marine debris, particularly fishing gear that can snag (Bauer et al., 2008). Topography of the seafloor influences the distribution of benthic marine plastic and can cause changes to the natural geomorphology (Corcoran et al., 2015). Additionally, low topography in the marine environment are areas where concentrations of marine plastic can accumulate such as submarine canyons (Galgani et al., 2000). Consoli et al. (2018) determined that the average abundance of marine debris increased in depths greater than 100m compared to shallow depths of less than 100 meters. Studies on the distribution of marine plastic debris can follow the similar pattern of high gradients coastlines and can show having increasing concentration of debris from the shoreline (Keller et al., 2010). Once in the benthic environment, bioturbation can alter the seafloor habitat through the process of fauna ingesting and moving MP in the sediment (Kristensen et al., 2012; Näkki et al., 2017). This process allows vertical distribution of microplastics in the benthic environment (Näkki et al., 2017).

1.2.5 Effects of Sunken Marine Plastics

The impacts of marine plastic in the benthic environment are still largely unknown, due to a research gap in environmental benthic studies. There is the potential that marine plastic can impact the carbon cycling in the oceans affecting the benthic environment by leaching dissolved organic carbon (Goldberg., 1997; Moore., 2008). Benthic plastic debris has the potential to cause anoxia and hypoxia due to smothering of sediments limiting gas exchange (Goldberg., 1997; Gregory & Andrady., 2003; Moore, 2003). Plastics can physically change the benthic composition causing benthic organisms to become smothered (Katsanevakis et al., 2007; Moore., 2008).

Marine organisms may also be impacted by benthic marine plastic through different factors such as ghost fishing which, while non-intentional, entangles marine organisms through lost fishing gear, leading to restricted movement, amputation, and potentially death (Marine Debris Entanglement Report., 2014; Sá et al., 2016).

Ingestion of marine plastics can also cause harm to a variety of organisms and can biomagnify throughout the food web (Bergmann et al., 2015; Farrell and Nelson., 2013; Setala et al., 2014). Plastic additives used in the production process can transfer to organisms' bloodstream, affecting physiology (Browne et al., 2013). Absorption of chemicals from the environment can also cause toxicological impacts (Espinosa et al., 2016; Rochman et al., 2014). Desorption of these chemicals from plastic debris can enter the organism and then enter into the food web (Andrady, 2011).

1.2.6 Benthic Plastic Pollution Methods

There is limited research and literature on benthic marine plastics compared with other types of marine environments due to costs and accessibility. Existing studies have been conducted using video footage, sediment sampling, deep sea trawling, snorkeling, SCUBA diving, and sonar (Bergman & Klagues, 2012; Galgani et al., 2014; Miyake et al., 2011; Schlining et al., 2013; Splenger & Costa, 2008; Watters et al., 2010). Yet comparing different studies of deep sea benthic marine debris is challenging, as methods have not been standardized; some camera studies use transect length rather than area covered, others use video footage instead of still photographs, others yet use bottom trawling (Galgani & Andral., 1998; Van Cauwenberghe et al., 2013). Analysis by camera focuses on macroplastics rather than microplastics, unlike sediment analysis (Bergmann & Kalges., 2012; Bergmann., 2015). Overall, this means that different studies are not readily comparable. In order for studies to be comparable, standardizing methods and data analysis for study areas that are similar in geomorphology and accessibility would be required. For example, collecting benthic data in rocky areas would not work for trawling or grab sampling for marine plastics as equipment would not work well or would be damaged (Corcoran et al., 2015; McWilliams et al., 2018).

1.2.7 Benthic Sediment Methods

There are different benthic sampling methods for microplastics that have been conducted in research. A common method of collection is benthic trawling collects macroplastics with varying mesh sizes (Galgani & Andral., 1998; Van Cauwenberghe et al., 2013). However, benthic trawling is an intrusive method of data collection due to the destructiveness to the natural environment (Galgani et al., 2015). Studies using ROV analysis are less invasive and can provide alternatives (Bergmann., 2015). At the same time, deep sea benthic marine debris may be under-estimated through methods of still photographs and video analysis due to burial by sediment and overgrowth (Bergmann & Kalges., 2012). The use of both video and sediment sampling represent a more accurate amount of marine plastic in the benthic environment (Bergmann & Kalges., 2012). These methods will be covered more in depth here.

Sediment analysis is a common method to determine the amount and types of debris found on the seafloor. Nearshore, deep sea, and beach sediments have been analyzed to determine the amount and types of marine debris. Benthic sediment samples in particular are used to determine the types and amounts of marine debris to determine what sinks. Benthic sediment sampling is a less common method of studying the distribution of marine debris due to cost, accessibility, sampling challenges (Bergmann & Klages., 2015). Trawling is an effective method to collect marine debris, however, it is highly destructive to the natural environment, is unable to be used in rocky or hard bottom locations and tends to underestimate the amount of marine debris due to the relatively large mesh sizes of trawls. It can also be a form of plastic contamination in samples from trawl netting fragmentation (Bergmann & Klages, 2015).

Other common methods that are less intrusive than trawling are using box corers and grab samples which can be conducted at varying depths (Claessens et al., 2011; Fisher et al., 2015; Katsanevakis et al., 2007; Ling et al., 2017; Martin et al., 2017; Nakki et al., 2017; Woodall et al., 2014). Sample collection methods differ between studies dependant on location geomorphology and depth.

1.2.8 Benthic Video/Photo Methods

There are different technical methods of collecting seafloor video and photos, including remotely operated vehicles (ROV), towed cameras, still photos, manned submersible vehicles, and underwater cameras used by scuba divers (Pham et al., 2014). ROVs do not require human presence underwater, can operate during day and night conditions, and can be fitted with additional features and mechanisms that may aid in sampling (Mallet et al., 2014). ROVs offer a high resolution colour camera, a laser scale with 4 lights, and additional cameras at different angles (Rodríguez & Pham., 2017).

ROVs offer video, photos, and sample collection. This method of video collection is expensive and requires experienced personnel to operate. ROV video collection is the main method used for deep sea video footage in MPP research (Melli et al., 2017; Mordecai et al., 2011; Pham et al., 2014; Woodall et al., 2015). This method provides quality video and photo images for identifying benthic debris. The difficultly of this method is the cost associated with renting the ROV for research, which can be exacerbated in remote, northern locations. Submersible vehicles and scuba diving are other less common methods for collecting video of seafloor debris (Morris et al., 2016; Waller et al., 2017; Watters et al., 2010;). Another method for collecting videos of seafloor debris is through underwater cameras that are mounted to the seafloor called Baited Remote Underwater Video (BRUV) which obtain video over a set amount of time (Dunbrack and Zielinski, 2003; Mallet et al., 2014;).

Video transects are another common method for collecting data of debris on the seafloor (Bergmann & Klages, 2012; Buhl-Mortensen & Buhl-Mortensen, 2017; Katsanevakis et al., 2007; Lundqvist., 2016; Pham et al., 2014). Video transects are performed with an underwater camera affixed on a structure that can be towed along the designated transect line. Cameras can be positioned at different angles providing different views of the seafloor (Buhl-Mortensen & Buhl-Mortensen., 2017). However, Galgani & Andral (1998) found that towed video photography was unsuccessful at consistently identifying marine debris due to positioning, altitude, speed and light availability at depth.

Another collection method is capturing still photos along a transect for benthic debris. Bergmann and Kalges (2012) used photos along a transect, collecting still photos in 30-50 second intervals. Photos that were too dark, had sediment clouds obstruction, or were taken at too high an altitude above the seafloor were omitted from the total area covered (Bergmann & Kalges., 2012). The length of litter was measured (longest dimension) and grouped into categories based on size: small (<10 cm), medium (10–50 cm) and large (>50 cm) (Bergmann & Kalges, 2012). The material was identified, if possible, based upon photo resolution. Bergmann & Kalges (2012) recorded signs of harm if epibenthic megafauna species interacted with the litter using categories of entangled or attached.

This study used a drop video camera system: specifically, a GoPro camera in a waterproof housing, with laser pointers for an underwater scale. The GoPro was deployed attached to a surface-feed standard definition video camera with live feed to the surface, such that the camera could be kept at near-constant altitude above the sea floor (see 2.1.5 Video Recording of Macroplastic on Seafloor).

1.2.9 Intertidal Plastic Debris Methods

Intertidal marine debris surveying helps identify the quantity and types of debris found in proximity to human settlements. Intertidal surveying could help determine potential point sources from coastal populations and any debris that is washed ashore (Browne et al., 2015). Intertidal zones are studied due to the accessibility, environmental impact, and the impact on aesthetic issues for the area (Browne et al., 2015). Marine debris in the intertidal zone can pose a threat to the health of the ecosystem through smothering and preventing sunlight to reach the environment (Bergmann & Klages, 2012). Environmental factors such as wind, tidal action, and changes to currents can bring marine debris to intertidal zones even in remote places (Browne et al., 2015). Shoreline and sediment analysis methods are commonly used for intertidal sampling (Browne et al., 2015; Mathalon & Hill., 2014; Moore et al., 2001)

The use of transects is a common method to determine the types and amounts of debris in the intertidal zone, however, methods vary when using transects (Browne et al., 2015). This study closely followed NOAA's shoreline study method (Opher et al., 2012), the basis of most standardization in the field, to ensure replicability of future studies. The NOAA's shoreline methodology uses a cross section of the tidal zone starting at the high-water mark which is closest to a potential point source from land. Opher et al. (2012) used strandlines running parallel to Frobisher Bay to collect debris along a 90m transect with 1m by 1m quadrats every 2 meters distance along the transect. Debris (>2 cm) was collected from visual identification within the quadrats and was counted, bagged, and tagged for laboratory classification, which was modified from Brown et al., (2010). See **2.1.7 Intertidal Survey** for details.

1.3 Study Area

Nunavut, which means "our land" in Inuktitut, is the traditional homeland of the Inuit. The capital, Iqaluit was formally known as Frobisher Bay and renamed in 1987. The 19th century brought British colonial explorers that laid claim to Inuit land. However, Nunavut officially became a part of Canada in the 1880. In the mid 1950's, the military influence brought change to Nunavut and impacted the life and of the Inuit. The Nunavut Land Claims Agreement and the Nunavut Act were passed in June 1993 and by April 1999 Nunavut became the newest Canadian territory (Kikert., 2021).

Iqaluit is positioned at latitude 63° 45’ N and longitude 68° 31’ W and is considered within the Canadian Arctic. The Canadian Arctic region has the potential to be affected by benthic marine plastics as a of result fishing industry and coastal cities. Communities that are within proximity to the ocean pose a concern for marine plastic pollution. Iqaluit is the largest city in Nunavut, the population of Iqaluit in 2016 was 7,740 (Statistics Canada, 2017). Iqaluit is a coastal community that heavily relies on the ocean for food, a source of income, transportation, import, and recreational use. Wastewater is carried through piped and truck collection to a treatment plant with effluent discharged into the natural environment (Krumhansl et al., 2014). Iqaluit’s landfill opened in 1955 (Nicholson., 2018) and was constructed with no lining, which has infrastructure implications causing leakage (Krumhansl et al., 2014).

Iqaluit has seasonal prevailing winds, in the winter north-west, and south-east in the summer (Hudson et al., 2001; Nawri & Stewart., 2006). Iqaluit experiences freeze up in late fall starting in October with break-up the in the spring beginning in the April (Forbes et al., 2018). Frobisher Bay inlet has a macrotidal, semi-diurnal and spring tidal range approximately 12 metres (Hatcher & Forbes., 2015; Samuelson., 2001). In 2016, there is no deep-water port for ships to offload and therefore, freights arriving in Frobisher Bay are offloaded by barge and brought in during low tide.

The study area is an important region to understand for potential marine debris found in Frobisher Bay from a land source such as the landfill. Therefore, the study region being examined is close to coastal communities. Frobisher Bay, especially near Iqaluit, is an area of interest for marine benthic plastic since there is an open and unlined landfill that has historically been on fire in proximity to the Bay (Weichenthal et al., 2015). This landfill is a potential point source for marine debris to enter the water and has the potential to pose harm to marine organisms and alter the natural habitat. Waste Management includes an open dump that recently was on fire which poses environmental concerns with leeching (Krumhansl et al., 2014). Iqaluit implemented a recycling program however due to cost of collection and shipping the materials out the program was discontinued (CBC News., 2010). The Nunavut Coastal Resource Inventory was conducted in Iqaluit, Nunavut, conducting interviews from elders and active hunters to collect data on both animal and plant resources to map to Fishing is an important food source and employment in Iqaluit. Nunavut fisheries for commercial and recreational fisheries major catch is for turbot (*Reihardtius hippoglossoides*), shrimp fisheries (Northern or pink shrimp – *Pandalus borealis*, and Arctic Char have been established offshore in the Baffin region (Government of Canada., 2012). During low-tide, people fish and forage in the intertidal zone.

This thesis focused on marine plastic pollution in the benthic environment to determine a baseline of quantity and composition of debris found near Iqaluit, Nunavut. The study looked at plastic pollution that sinks to the seafloor for microplastics through video recording of the seafloor for macroplastics and sediment grab samples for microplastics. An intertidal survey was conducted to determine the quantity and classification of debris in the area. The methods for collection and analyzing for plastic debris for benthic studies have not been standardized in literature and therefore methods were chosen and adapted for easy replication for future research. This study aims to create a baseline for the amount and types of plastic pollution found in the benthic environment near Iqaluit, NU.

1.4 Scientific Questions

1. What are the amounts, types, and distribution of anthropogenic debris in Frobisher Bay?

   Test: Examined 2016 and 2017 seafloor video footage to determine the amount of macroplastic and sediment grab samples to analyze for microplastics in Frobisher Bay. Field collection was conducted in the fall of 2017 for seafloor video footage and benthic sediment samples to examine the amount of macroplastic and microplastics found in Frobisher Bay. Similar field methods and field work was conducted in 2016 from another thesis study and samples and videos from 2016 were analyzed to compare across two (2) years.

a) How does Iqaluit's waste management and infrastructure impact the amount and types of microplastic found in Frobisher's Bay?

   Prediction: Iqaluit's open dump will result in anthropogenic debris including marine plastic entering Frobisher Bay with having an open dump close to the head of the Bay.

   Test: Used a shoreline survey near the landfill to determine if there are identifiable landfill materials on the shoreline.

b) How much lost fishing gear does Iqaluit's fishing industry impact the marine habitat?

Prediction: Commercial and recreational fishing is a major source of food for Iqaluit which has the potential in the loss of fishing gear in Frobisher Bay, which could cause have potential to create marine debris entering the natural environment.

Test: Seafloor analysis for marine plastic and anthropogenic debris was conducted through video recordings for 4 minutes per site in 2016 and 2017, with attention to plastics related to fishing activities.

2.0 Methods

To determine the amounts, distribution, and types of marine debris in Frobisher Bay, Iqaluit, three different methods were used to sample various sites of interest and environmental media: 1) a Van Veen grab sampler was used to collect benthic sediments in shallow waters in Frobisher Bay near Iqaluit. Accompanying this; 2) at each site an underwater drop camera and GoPro recorded video of the seabed for visual analysis of macroplastics, and; 3) in an intertidal zone close to Iqaluit, a shoreline survey was conducted. Each method provided different insights into marine debris in a complex landscape.

2.1 Field Methods

2.1.1 Selection of sampling sites

Proposed sites were selected to sample for marine plastics in inner Frobisher Bay, radiating into the Bay from the settlement of Iqaluit.

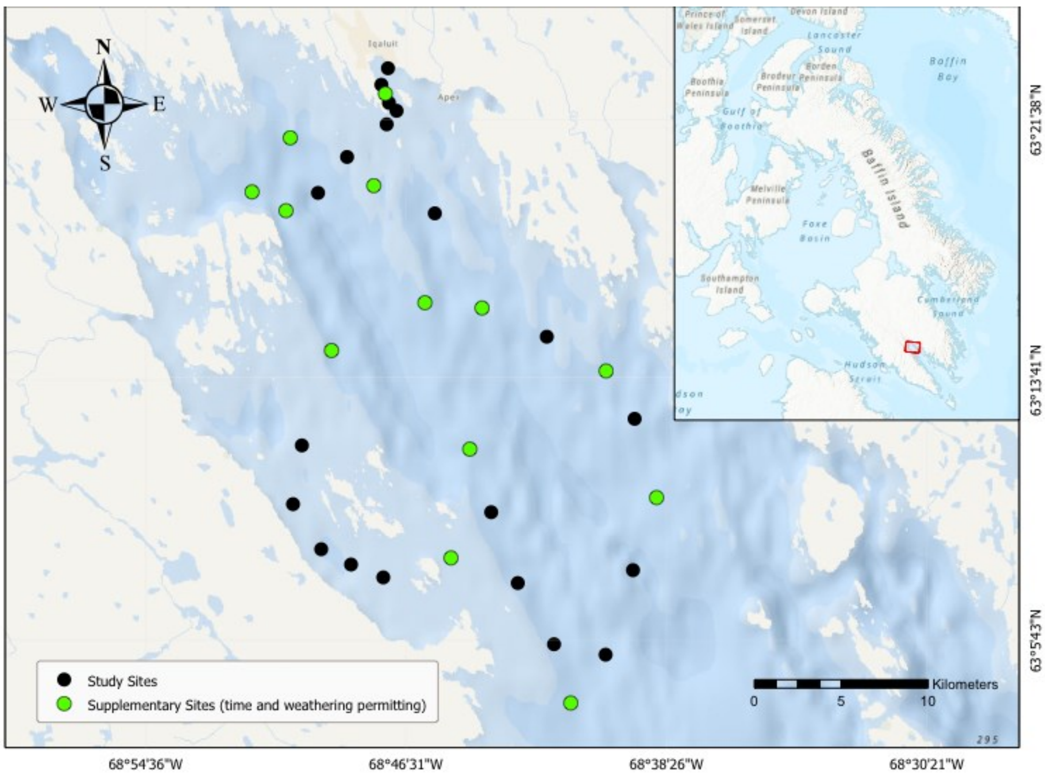

Figure 1 Proposed study sites for benthic grab sample and seafloor video for 2017 created for the 2017 MV Nuliajuk Cruise Report for the Government of Nunavut with supplementary sites if time and weather permitted. See Figure 2.1.6 for final study sites.

The sample sites for the 2017 sampling period were selected based on the Nunavut Government's Nunavut Coastal Resource Inventory (NCRI) report. The NCRI was conducted by the Fisheries and Sealing Division of the Department of the Environment (DOE) to interview active hunters across Nunavut to understand the local fishing and hunting areas. In 2012, the NCRI conducted interviews in Iqaluit, NU to collect resource inventories for animals and plants in 26 coastal communities. Based on this report the sampling sites were chosen in areas of high human activity such as fishing spots, shipping lanes, and proximity to camps. Sites were also selected to be in proximity to the open landfill to establish a baseline as a potential point source. To complement nearshore benthic sampling, an intertidal survey was completed to determine the types and amounts of debris found in this area which is used for bringing in ship barges to land and is proximal to high human activity.

2.1.2 Benthic Study Areas

Benthic sample sites were selected based on the areas most used by hunters and camp sites. These included 36 initial sites with 13 priority sites and 23 supplementary. In total, 11 of 13 priority sites for the grab and video sites were collected and no supplementary sites were used due to restricted boat time related to weather. In some cases, there was no return in the grab sampler and so only video was collected at a site.

2.1.3 Intertidal Survey Study Area

The intertidal survey was initially to be conducted at the Iqaluit landfill, but it was relocated to an area proximal to the landing beach for sealift barges because the initial location was unsafe. There is a large drop-off at the water's edge of the landfill and there was no flat or safe area from the landfill to Frobisher Bay to conduct a land survey. The new intertidal location at low tide was selected as it is a flat area and is an area of high human activity as it is the location where barges are brought in from the ships. The intertidal survey was conducted to determine the amounts and types of land debris that may enter Frobisher Bay as a possible point source for marine plastic pollution.

2.1.4 Benthic Grab Sampling

Benthic sample collection in 2017 was part of a 2-day sampling on Leg C of the cruise aboard the *MV Nuliajuk* Fisheries Research Vessel, owned by the Government of Nunavut Department of Environment and Conservation, Fisheries and Sealing Division. Due to inclement weather, only one and a half days were conducted out of the designated two full days of data collection.

Benthic grab sampling was conducted using a 24 L *Wildco* Van Veen grab sampler. The grab sampler was lowered from the boat to the seafloor and pulled up by the boat winch. Subsamples were collected by obtaining 90ml (3.0 oz) volume of sediment into sampling jars for later analysis for microplastics.

This study also opportunistically used grab samples collected in 2016 from another study to increase the sample size and potentially enable analysis of trends over time. During 2016, ethanol was added to grab samples to preserve any species for previous thesis objectives. However, ethanol was not used in 2017 samples, which were just for plastic analysis, to avoid using toxic chemicals. In 2016, grab samples were collected in the same way as 2017 with minor differences which included each grab sampler in 2016 was emptied and sieved through 0.5 mm mesh screen on the boat to remove fine residue from sediment which was also collected for other research objectives. The samples were stored in an 70% ethanol solution for archiving. The grab samples collected in 2017 were collected directly from the Van Veen grab sampler and no sieving was conducted on site, nor were chemicals added for archiving. This was to reduce the amount of water overflow over the top of the sieve which could potentially contain microplastics which would not be represented for 2016.

No plastic contamination protocol was conducted during the 2016 sampling as this research was from a previous thesis study that did not involve plastics. During data collection in 2017, plastic contamination controls included wearing a survival floatation suit over clothing along with wearing no fleece when on deck. An open petri dish with double sided tape (a blank) was used to collect airborne plastic fibers while samples were being collected from the boat. Sediment collected from the grab sampler was collected by one person, with limited exposure time, and no fleece was worn during collection. See the section on differences in sampling protocols below for more details.

During sample collection in 2017 onboard the MV *Nuliajuk,* daily observations of activities for deck operations and waste disposal were recorded to help inform ideas around sources of plastic contamination and debris.

2.1.5 Video Recording of Macroplastic on Seafloor

Video footage was collected at the same sites as benthic sediment samples by a *Deep Blue Pro* drop underwater camera with standard definition with a *GoPro* (*Hero 4)* encased in a GroupBinc ScoutPro H3 underwater housing, which provided high-resolution in 4k video for analysis which was deployed from the boat. Two laser points spaced five cm apart are visible in all video drifts for scale. Videos were recorded for 4-minute intervals and drifted at the sample site. This is similar to Buhl-Mortensen & Buhl-Mortensen's methods (2016) which used an underwater camera to capture footage of benthic debris and followed a 700m transect. However, this thesis did not follow a linear transect due to potential damage to the underwater camera being towed but drifted with the boat.

2.1.6 Differences Between 2016 and 2017 Sample Collection

Because this study used some samples collected for another study, different research objectives resulted in different methods for sampling during 2016 and 2017. In 2016, the methods were identical with the exception that there was no contamination control collected during sample collection, and the benthic grab samples were sieved by using water using a 0.5 mm mesh screen which removed fine grain sediment. In 2016, sediment samples were collected in jars with 70% ethanol added to preserve samples for different research objectives. Sediment collected in 2017 did not add any ethanol to sample jars. Methods of video recording did not differ between the two years.

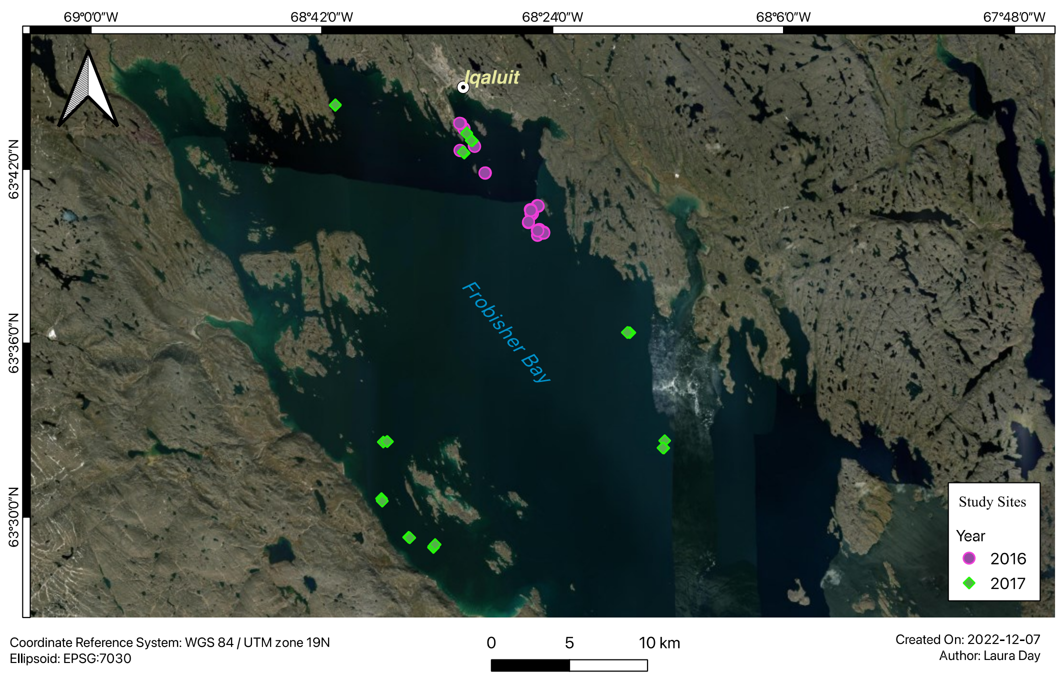

Figure 2 Final study sites for benthic grab and video sampling for 2016 and 2017 in Frobisher Bay, Iqaluit, NU.

2.1.7 Intertidal Survey

On October 19, 2017, an intertidal survey was conducted in collaboration with second year students from the Environmental Technology Program participated as research assistants during low tide. Methods were adapted from the *Shoreline Field Guide* produced by Opfer et al. (2012) to conduct an accumulation survey. The group observed and recorded the characteristics of the landscape being analyzed, including the surrounding land-use and landscape characteristics (for example, whether a transect was nearest to the landfill, if areas were snow-covered). Characteristics of the land were recorded to identify primary substrate type and description of the first barrier (example vegetation, building etc.) following the methods outlined in Opfer et al. (2012). One transect of 99 meters was measured at the top of the intertidal zone parallel to Frobisher Bay and two other transects of the same length and orientation were measured at different barriers of sediment or vegetation going towards Frobisher Bay, areas where plastics are likely to accumulate. Every 2 meters, a 1m x 1m quadrat was placed along each transect. A total of 30 quadrats were sampled. Any type of debris within a quadrat was logged on paper, bagged and labelled with the quadrat number and transect number. All debris items were counted and categorized on site using the NOAA field guide data sheet (Opfer et al., 2012). Bagged debris and paper logs were later analyzed in the lab. Large debris that was unable to be collected was photographed. The intertidal zone was surveyed for debris along three transects running parallel from land to water. The three transects starting at the high watermark, closest to land (transect 1) mid zone (transect 2) and low zone which was closest to water in Frobisher Bay (transect 3). Transect 3 had the most macro-plastic debris while transect 2 had the least amount of debris found in total.

Figure 3 Intertidal Survey Site in Iqaluit, Nunavut, Canada.

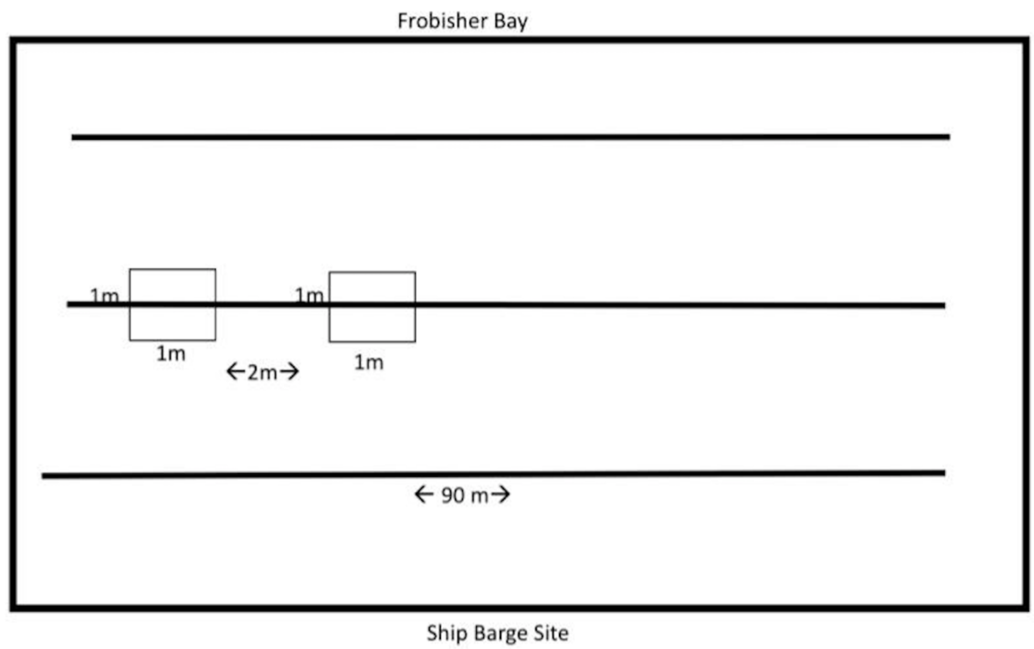

Figure 4 Intertidal survey transects from strandline to Frobisher Bay with two examples of quadrats.

Figure 5 Photo of intertidal survey. NRI students conducting quantification of plastic debris within the 1mX1m rope quadrat along transect parallel to Frobisher Bay.

2.2 Laboratory Methods

2.2.1 Contamination Control

Contamination during microplastic sampling and analysis from atmospheric deposition from synthetic textiles (microfibers) pose issues during laboratory analysis (Barrows et al., 2017; Bergmann et al., 2017; Hidalgo-Ruz et al., 2012). Steps to reduce laboratory contamination included: tie hair back, wear a cotton lab coat, cover equipment when not in use, rinse tools in water regularly, and have a control sample. This study used double sided tape in an open petri dish for a contamination control during sample processing, which aids in not overestimating microfiber counts by disregarding any microplastics that match in samples to the contamination control (Woodall et al., 2014). Between samples, sieves were washed with a dish sponge and air dried. Dish sponge control samples were added to the open petri dish to eliminate any potential contamination (Barrows et al., 2017).

2.2.2 Benthic Grab Sample Analysis

The grab samples collected in 2016 were stored in 70% ethanol. For processing, these samples were drained of the ethanol. The ethanol from samples were placed in a labeled waste container. The samples were then placed into a pan and dried in a *Quincy Lab 10GC Gravity Convection Lab Oven* (0.7 Cu.Ft., 115V 600W) with varying temperatures (100°F – 300°F). Drying time depended on the amount of sediment and water content but ranged from 30 minutes to 1 hour due to different sized sediment requiring more or less time to dry and was checked regularly. Once dried, sieves with 4.25 mm, 1mm, and 355 µm mesh with a bottom pan were stacked following the method used by Courtene-Jones et al. (2019) with additional mesh size sieves to account for larger marine debris (Lippiatt et al., 2013; Masura et al., 2015). The stacked sieves were shaken by hand to separate microplastics and sediment between sieves. Each sieve was visually analyzed for microplastics twice for accuracy. Any debris found was placed into a sample bottle.

Grab samples collected in 2017 differed in analysis due to the thick nature of the sediment. Unlike the 2016 samples that were sieved on the boat, the 2017 samples included fine grained sediment. Trial and error showed that drying in the oven produced solidified sediment that could not be processed at this state. These samples were wet sieved and shaken through stacked 4.25 mm, 1mm, and 355 µm mesh sieves with a bottom pan. The sample was placed on the top (4.25 mm sieve) and rinsed with tap water without overflowing the bottom pan. The sediment in the sieves were then physically separated by shaking until the sediment was separated by sizes. Each sieve was examined for debris twice. Identifying microplastics through wet sieving does not allow the microplastics to separate well from the sediment and therefore analysis took a longer time. Any found debris was placed in a sample container for later Raman Spectroscopy analysis.

The methods described above were used after many trials of different published methods to separate debris from sediment. Density separation is a method to isolate plastics from sediment by changing the densities. The saline solution float method is one non-toxic way to achieve density separation. A test of this method was conducted using gravel and rocks with different densities of plastics placed into a beaker with first cold and then warm distilled water with saline solution (NaCl) of 1.2 g mL 1 (50%) to distilled water (Imhof *et al*. 2012; Blašković *et al*. 2017). Vigorous manual shaking was used to separate plastics from sediment and allow plastics to float to the top of the mixture. This was unsuccessful as plastics with lower densities did not float.

A method commonly used for plastic debris in sediment is a float test which separates microplastics from sediment and is found in literature methods (Classens et al., 2011; Andray., 2011; Mathalon & Hill., 2014). This method was used, however, it was unsuccessful at retrieving all plastics in this project and I resorted to the much time consuming method of visual identification using microscopy. Regardless, the float method is outlined here.

The float test using saline water is used to separate microplastics from sediment to allow certain concentration plastics to float and identify from the sample. A control float test was preformed to determine if clean, plastic items with known polymers would float in a saline solution. Plastic items with lower densities did float during the test, which included: PP, polyester, LDPE, and HDPE. Plastics with higher densities did not float, which included: PVC, nylon, and PS.

Table 1 Saline solution performed with known plastic debris control samples.

Material	Float/Sink
PVC	Sink
PP	Float
Polyester	Float
LDPE	Float
Nylon	Sink
HDPE	Float
PS	Sink

Another float test was performed with ethanol (100%) to determine if certain plastics would float or sink. This method was used in Corcoan et al., 2009 and Morét-

Ferguson et al., 2010 to lower the concentration of the solution to make plastic samples that floated to sink. However, none of the plastics tested floated in this method.

Table 2 Float test for plastic debris (clean) in ethanol (100%).

Material	**Float/Sink**
PVC	Sink
PP	Sink
Polyester	Sink
LDPE	Sink
Nylon	Sink
HDPE	Sink
PS	Sink

Dry separation was also attempted. A custom-built sediment shaker was created out of a discarded orbital shaker that held the sieves in place to attempt to sperate plastics from sediment. This method was unsuccessful. This machine was unable to shake hard enough to separate different size classes of sediment through the stacked sieves. Shaking by hand for 2 minutes was more effective to separate sediments and debris into different size classes. Thus, hand shaking followed by visual identification of plastics under a microscope was used for this thesis project.

2.2.3 Benthic Video Analysis

Video analysis was the same for the 2016 and 2017 cruises. Both GoPro and standard definition videos were visually analyzed for macroplastics. All anthropogenic debris was that was visually identifiable was recorded. Marine debris was recorded through the categorization and characterization by Van Franeker (2004), Bergmann & Kalges., (2012), and Corcoran et al., (2009).

Debris items that were identified were catalogued with a still photo from the video along with the latitude and longitude recorded. Seafloor video analysis was conducted for

20 minutes with a 5-minute break to reduce eye fatigue from screens and to be more alert to observe small objects (Bailey., 2014). Debris that was difficult to identify due to low resolution or low light was not included in the count of debris found.

2.2.4 Raman Spectroscopy

All debris found in the grab samples were analyzed with Raman Spectroscopy to identify polymer type. This method was chosen because the shape, size, and thickness of the plastic does not limit polymer identification unlike Fourier Transform Infrared Spectroscopy (FTIR) which is affected by these factors. Raman and FTIR both identify the spectra of the plastic debris item to give similar results by vibrational spectroscopy; Raman using a scattering method through a monochromatic light and FTIR using Infrared (IR) radiation (Käppler et al., 2016). References of Raman spectroscopy of plastic debris and organic material were used to determine how close the debris found in the grab samples were to the references. This was difficult as the references rarely use marine plastic debris for analysis rather the references are based upon pure plastics. A close visual match to similar spectra peaks was used to determine polymer type and plastic debris from organic material.

2.2.5 Intertidal Survey Analysis

Collected debris items were photographed, dried, and then weighed and measured. A drying oven was used to dry large debris. However, three debris items were burnt and unable to be weighed and measured, but photos remain. Photos can be found in **Appendix 4.** Intertidal Survey Macrodebris in Iqaluit, NU 2017

Chapter 3: Results

3.1 Benthic Sediment Grab Samples

In both 2016 and 2017 sample years a total of 19 anthropogenic debris items were found in nine of the total 55 benthic sediment grab samples (Table 3). Of these 55 sites, 44 were from the 2016 sample collection, and though 13 sites were selected for priority sampling in 2017, only 11 were collected due to weather and boat time constraints.

The frequency of occurrence of all anthropogenic marine debris appearing in each site is 16% (9/55), with a frequency of occurrence of 13% for plastics specifically (7/55). For samples gathered in 2017 for which concentration measures are possible, the average concentration of all sites is 0.0017 plastics/mL of sediment, with a median of 0. A total of 14 of the 19 debris items were plastics, two were glass, and three were carbon steel.

The morphology of benthic plastics was mainly fragments (71%, n= 12), with some threads (18%, n=3) and film plastic (12%, n=2). There were no industrial pellets, microbeads, foams, or microfibers. The average longest dimension of all anthropogenic debris (length in Table 3) was 13.17mm, with a median of 4.58mm, both of which fall into the macroplastic size class. For the plastic debris, the average longest dimension was 13.74mm and the median was 5.25, which categorize into macro size classes, however, 42% of all plastics were microplastics. The high average sizes are due to do several very large items.

The most common colour in the benthic grab debris was white (31.6%). The common opacity for debris found was opaque (78.9%). Both slight transparency and transparent debris was 10.5%. There was only one debris found that was melted/ frayed ends which accounts for (5.3%) of debris found. The most common debris that was found showed signs of weathering by frayed ends and or discolouration (52.6%). Debris that was determined carbon steel showed signs of weathering through discolouration and pitting.

Table 3 Anthropogenic debris from benthic sediment samples in 2016 and 2017 from Frobisher Bay, Nunavut.

Site	Year	Debris Type	Polymer/ Material	Morphology	Mass (g)	Length (mm)	Size Class
A-25	2016	Plastic	Polyethylene (PE)	Film	0.0108	28.25	Macro
		Plastic	PE	Thread	0.0036	31.95	Macro
A-28	2016	Plastic	Polycarbonate	Fragment	0.0003	2.93	Micro
		Non-plastic	Carbon steel		<0.0001	1.43	Micro
A-5B	2016	Plastic	Polyvinyl chloride (PVC) and gypsum	Fragment	<0.0001	2.35	Micro
		Plastic	PVC and gypsum	Fragment	<0.0001	2.42	Micro
		Non-plastic	Carbon steel		0.0009	1.59	Micro
B-5	2016	Non-plastic	Glass		1.4195	26.85	Macro
		Non-plastic	Glass		1.883	26.88	Macro
B-5A	2016	Non-plastic	Carbon steel		0.003	1.66	Micro
B-5C	2016	Plastic	Undetermined (likely PE)	Thread	0.0003	2.91	Micro
		Plastic	PVC and gypsum	Fragment	0.0037	3.91	Micro
		Plastic	PVC and gypsum	Fragment	0.0011	5.43	Macro
		Plastic	PVC and gypsum	Fragment	0.0015	6.85	Macro
FB2-2	2016	Plastic	Undetermined	Fragment	0.0109	77.82	Macro
		Plastic	PVC	Film	0.0005	5.25	Macro
		Plastic	Polycyclic aromatic hydrocarbons (PAHs)	Fragment	0.0131	7.3	Macro
IFB-2	2017	Plastic	Undetermined (likely PE)	Thread	<0.0001	1.2	Micro
IFB-6	2017	Plastic	Undetermined	Fragment	1.8629	-	-

Several sample stations warrant particular attention in terms of the debris found. Sites B-5C and A-5B, both close to Iqaluit had the most plastic debris (see Figure 9). At station B-5C, one green thread was found with signs of weathering of frayed ends, likely from fishing gear. Station B-5C also included three plastic fragments composed of fibrous material that showed signs of discolouration and frayed ends. Raman analysis indicated these were made of PVC and gypsum, and all three likely came from the same source (**Appendix 2.** Benthic debris photos found in grab samples in Frobisher Bay, Iqaluit, NU in 2016 and 2017). A-5B had two of the same PVC gypsum fragments, as well as a fragmented piece of carbon steel.

Site B-5 from 2016 had two non-plastic anthropogenic debris items. These were two broken small glass vials with limited weathering, as writing on the vials were still readable:

Figure 6 Anthropogenic debris found in Benthic Grab Sample in 2016 in Frobisher Bay, Iqaluit, NU. Grid paper is 1cm x 1cm. Label on vials read New England Nuclear NEC-086s NaHC14O 1.0mL Sterile H2OpH9.5 L01 No. 670-079 10.0 µCi 100.0 µgms.

Paint contamination was identified in sediment samples from benthic grab samples. There was a total of 53 blue paint items with a total weight of paint contamination was 0.0181g. This paint was considered contamination as it was the same colour of the research vessel, the MV *Nuliajuk*. They were removed from the sample and are not recorded in the figures above.

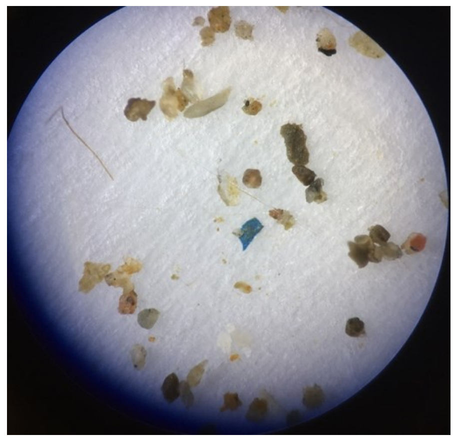

Figure 7 Blue paint contamination in benthic samples from Frobisher Bay, Iqaluit, NU.

3.1.1 Benthic Sediment Concentration

Concentration (number of plastics per millimetre of sediment) was calculated for each site in terms of the total sediment sampled across replicate grabs. In 2017, four of the 11 grab sample collection sites did not recover all three replicate samples. Sample site IFB-8 returned no sediment samples because two grab samplers returned only rock and therefore no sediment was collected. This site was skipped to move on to the next sample site due to time. The other sample sites IFB-2, 7, and 9 only had two sediment samples collected because the third or fourth grab sampler attempt only brought up rock.

Table 4 Anthropogenic debris found in 2017 benthic sediment in Frobisher Bay, Nunavut collected by a grab sampler and subsampled for 50ml per replicate at each sample location.

Site	Number of Anthropogenic debris	Number of Plastic Debris	% plastic	Number of Replicates	Total Volume Sampled	Plastic Concentration (#/mL)
IFB_2	1	1	100%	2	100	0.01
IFB_6	1	1	100%	3	150	0.007
IFB_1	0	0		3	150	0
IFB-3	0	0		3	150	0
IFB-4	0	0		3	150	0
IFB-5	0	0		3	150	0
IFB-7	0	0		2	100	0
IFB-9	0	0		2	100	0
IFB-10	0	0		3	150	0
IFB-11	0	0		3	150	0

The average concentration of all 2017 sites is 0.002 plastics/mL. The median is 0. As mentioned in the methods section, different sample amounts in 2016 were collected from the grab sampler that resulted in the loss of fine sediment, and therefore no concentration was determined due to not knowing the original volume of sediment.

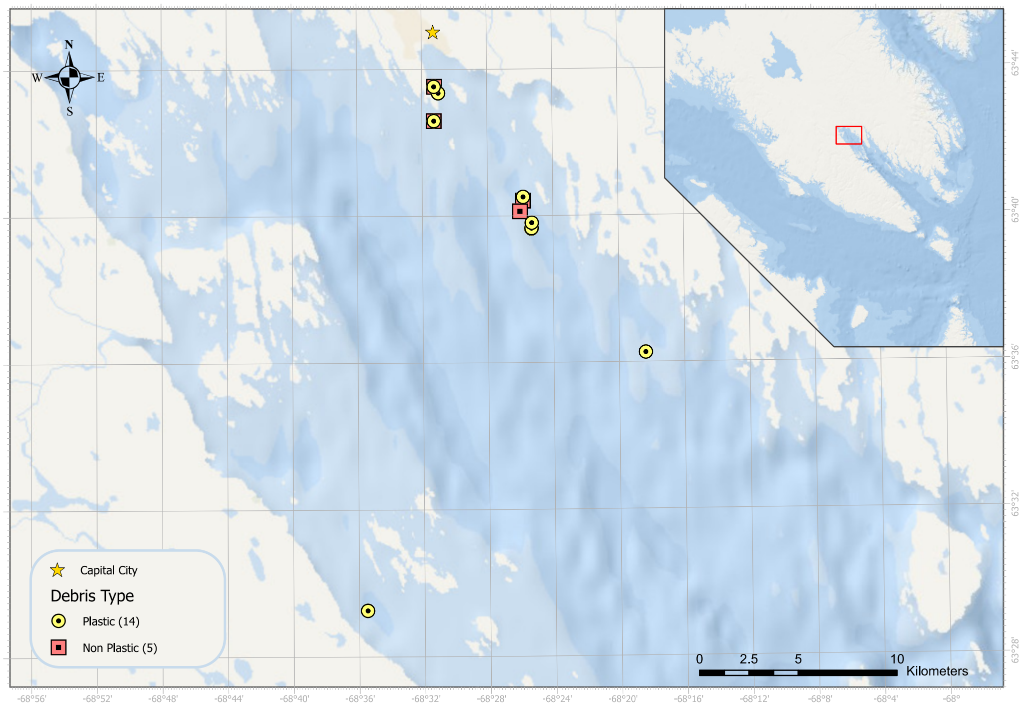

Figure 8 Found anthropogenic debris (non-plastic) and plastic debris in Frobisher Bay, Iqaluit, NU for 2016 and 2017.

3.2 Benthic Video for Macroplastic Debris

A total of 54 underwater videos were visually analyzed to identify macroplastics in the benthic environment in Frobisher Bay. In 2017, only 10 of the 13 videos were useable due to technical issues, batteries, and clarity of videos. From 2016, 44 videos were analyzed. Of the 54 sites, only three contained anthropogenic debris, a frequency of occurrence of 5% (3/54). These sites contained 13 items, all plastic except one. All debris was found in the 2016 videos. The average concentration of all sites is 0.055 plastics/minute with a median of 0. However, 11 items came from a single site: A-5B (63.72559833, - 68.52117333), which had a concentration of 2.75 plastic items/minute, while station A-26 (one plastic) and D-IF31 (one non-plastic) had densities of 0.25

items/minute. All anthropogenic debris identified from video footage were macroplastics see Table 5.

Table 5 Found macro anthropogenic debris in benthic videos in 2016 Frobisher Bay, Nunavut.

Station	Year	Debris	Type	Lat	Long
A-26	2016	Plastic	Unknown	63.7131283	-68.503133
A-5b	2016	Plastic	Bag	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
A-5b	2016	Plastic	Fishing line	63.7255983	-68.521173
D-IF31	2016	Non_Plastic	Unknown	63.536985	-68.259413

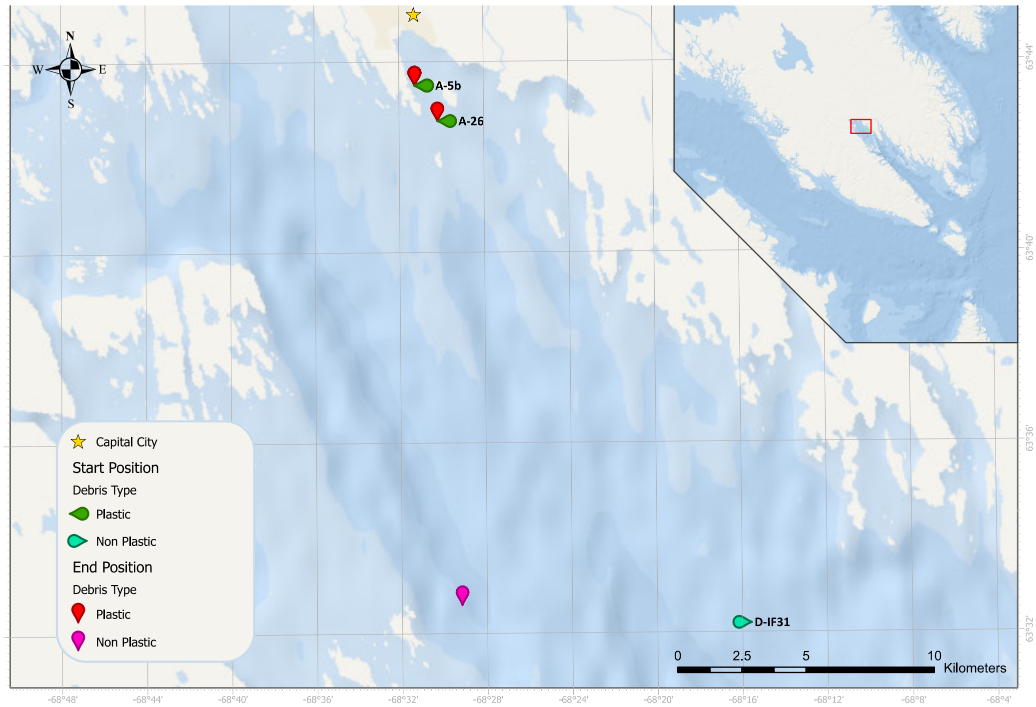

Figure 9 Found anthropogenic debris (plastic and non-plastic) benthic video debris in Frobisher Bay, Iqaluit in 2016 and 2017.

3.2.1 Comparison between 2016 and 2017 Samples

Statistical analysis of whether there was a temporal trend of increasing or decreasing abundance of plastics between 2016 and 2017 data collection in grab samples showed no significant trend. A t-test was performed through the program *R* to determine that there was no significant trend between the two sampling years. Both the linear model with log transformation and generalized linear model with negative binomial error had similar results and found non-significant p-values. The p-value for benthic grab plastics was 0.0558, and for anthropogenic debris was 0.0146. The p-value for benthic video plastic debris was 0.2744 and for anthropogenic debris was 0. Thus, the null hypothesis holds and there is no significant difference in the abundance of plastics between the two years of sample collection.

Had the results been significantly different, we would have had to consider the slight changes in sample collection, particularly the initial sieving of 2016 samples on the ship, as a potential source of the difference. However, given that there was no significant difference between years, we can assume that the slight difference in sample collection was also not significant.

3.3 Intertidal Survey

The intertidal survey of 30 1x1m quadrats along three transects recorded anthropogenic items in 13 of those quadrats. Frequency of occurrence (FO%), or the percentage of quadrats that had at least one anthropogenic item was 43%. Of those items, ten were plastic (59% of all debris) and 7 were non-plastic anthropogenic debris items (41% of all debris). The frequency of occurrence for plastics being found in a quadrat was 27% (8/30). Of non-plastic items, four were metal (24% of all debris), one was wood (6%) and one was an organic chicken bone (6%). This results in a concentration of 0.6 anthropogenic items per m^2, and a concentration of 0.4 plastic per m^2. Though microplastics were searched for, all plastic items were macroplastics.

Table 6 Found macro anthropogenic debris during intertidal land survey in Iqaluit, NU from 2017.

Quadrat	Transect	Debris	Colour	Length (mm)	Weight (g)
2	1	Metal	Brown	73.95	83.6487
2	1	Metal	Brown	180	9.823
3	1	Metal	Green	112.98	38.3752
4	1	Plastic	Yellow/Silver	19.69	0.0546
5	1	Other	N/A	N/A	N/A
6	1	Plastic	Blue	440	38.23
8	1	Plastic	White/Red/Yellow	111.15	0.1815
17	2	Metal	Brown	58.18	--
19	3	Plastic	White	32.89	0.0231
20	3	Cloth	White/Black	107.77	4.2734
21	3	Plastic	Brown	380	8.35
23	3	Plastic	White	35.52	--
23	3	Plastic	White	N/A	0.093
23	3	Plastic	White/Orange	17.7	0.0233
24	3	Plastic	Black	60.72	0.1103
28	3	Wood	Brown	--	--
30	3	Plastic	Black	--	--

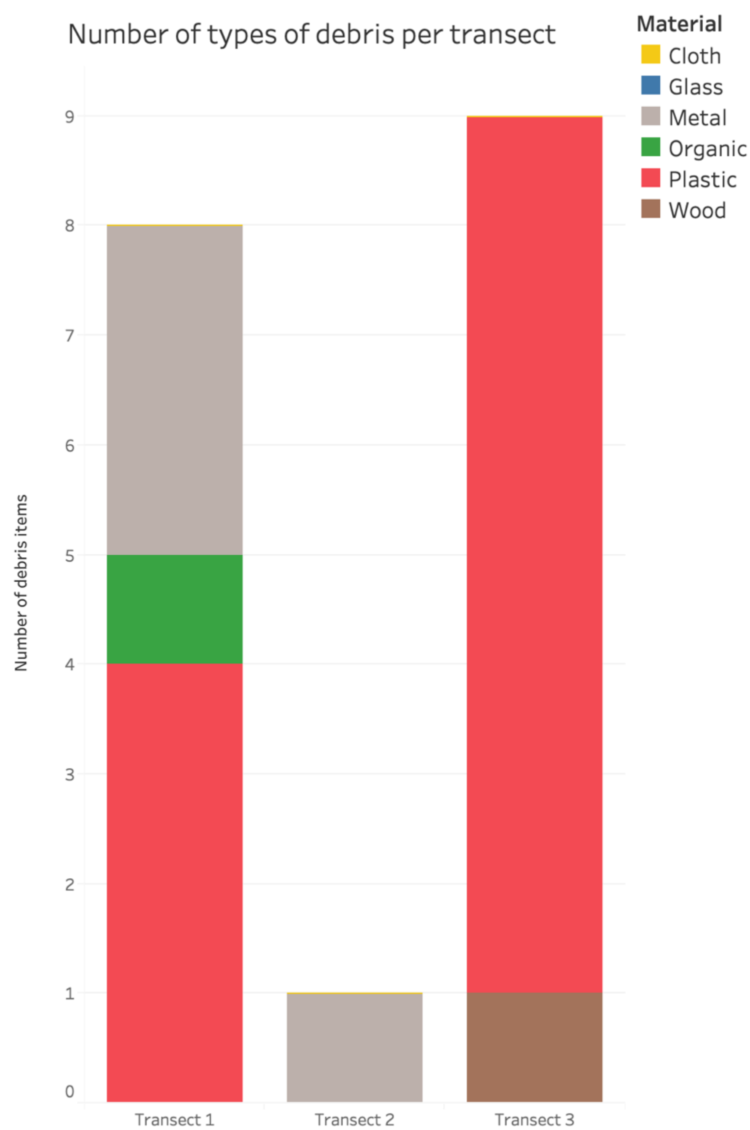

Figure 10 Anthropogenic debris found in the intertidal zone in Iqaluit, NU from 2017.

Transect 1 was at the high-water mark (closest to shore) and transect 3 was the low intertidal zone (nearest the water) had a similar number of items, while transect 2 (mid intertidal zone) had the least. All transects are under water when the tide comes in, so debris is likely to be caught in tidal movement. It's likely all debris is somewhat recently deposited since it had not been buried or swept out to sea.

The quadrat that had the most plastic was quadrat # 23 in transect #3, which is the closest to water during low tide. This transect (#3) had patches of vegetation acting as a barrier for plastics from being washed out during tide changes. Transect 3 is the farthest transect conducted from land. All debris found in quadrat # 23 in transect # 3 was all white macro-plastic debris with some signs of weathering. Two of the three debris items were food wrappers with colour. One of the debris items showed signs of having burnt ends. The quadrat that had the most non-plastic debris was quadrat #2 in transect#1, which contained two metal debris items. This debris showed signs of weathering by discolouration and erosion/rusting. This is the closest quadrat with debris found to an area of high human activity. There is a construction spot on land where all the ship barges are brought into shore.

3.3.1 Debris found in Transect 1

In Quadrat #2 there were two metal debris which showed signs of weathering. In Quadrat #3 a green metal debris was found see Figure 11. This item did not show signs of weathering.

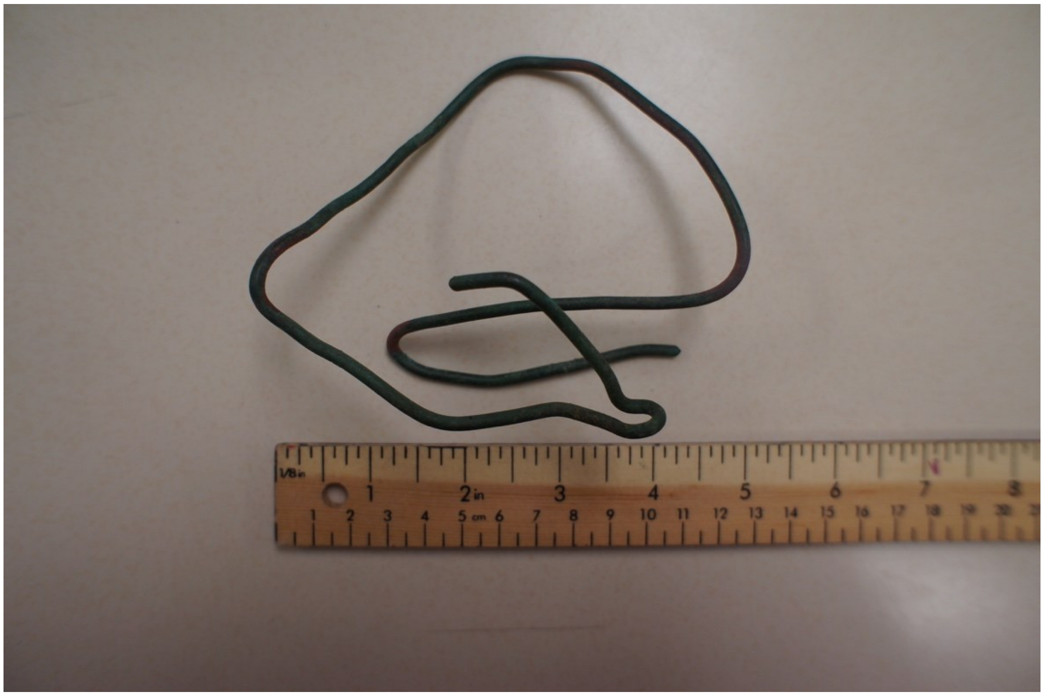

Figure 11 Green metal debris found in Quadrat #3 along Transect #1.

Debris found in quadrat #4 had a piece of foam with some duct tape stuck to it. Quadrat #5 had a chicken bone which was classified as other. Quadrat #6 had a plastic debris fragment which resembled a cut up tarp. Quadrat #8 found one plastic film from a food wrapper.

3.3.2 Debris found in Transect 2

Transect #2 had the least amount of debris recorded. The only debris found was in Quadrat #17 which consisted of one metal debris with signs of weathering.

3.3.3 Debris found in Transect 3

Quadrat #19 had one plastic film debris with frayed ends showing signs of weathering. Quadrat #20 had one rope (cloth) with knots and frayed ends. In quadrat #21 a plastic wax paper with colour discolouration. Quadrat #23 which had the most plastic debris consisted of white film, food wrapper, and another debris which melted upon processing. One black plastic bag fragment was found in quadrat #24. One wood debris was found in quadrat #28 with signs of some weathering. In quadrat #30 a black plastic bag was 1/3 full and intact.

Chapter 4: Discussion

In this chapter, results were compared to other studies and recommendations for next steps for similar research studies. Many of the methods in plastic pollution research are not standardized enough for a direct comparison between figures. However, there is enough overlap that some comparisons are possible. All three methods in this study, benthic sediment, benthic video, and intertidal quadrats had lower concentrations of plastics than other studies globally.

4.1 Summary of Results for Benthic, Camera, and Intertidal

Table 7 Results for each method collection showing the total number of samples, the frequency of occurrence (the number of anthropogenic or plastic debris found in each sample), concentration of plastics found, and size class of debris found for 2016 and 2017.

Method	Total samples (n)	FO% (all debris)	FO% (plastics)	Concentration (plastics/unit)	Size class
Benthic	55	16%	13%	0.002 objects/mL	Micro and Macro
Camera	54	5%	3%	0.055 objects/minute	Macro
Intertidal	30	43%	27%	0.379 objects/m^2	Macro

4.2 Comparison to other sites

Benthic studies for plastic pollution are less abundant due to cost, accessibility, and feasibility. Comparing this thesis to other studies is challenging due to the lack of literature, methods, and standardization of benthic studies. The amount of benthic debris found in Frobisher Bay, NU was lower than other benthic studies (see Table 7 and Table 8). The debris found in the intertidal zone in Iqaluit, NU was also lower than other intertidal surveys around the world.

The table below for comparison studies for intertidal, video, and benthic plastic pollution research. There is a lack of standardization between studies and therefore difficult to compare against this study.

Table 8 Literature review of benthic debris studies.

Author	Location	Year of Study	Year of Publication	Study	Method	Results
Fisher et al	Kuril–Kamchatka Trench area (NW Pacific)	2012	2015	Deepsea	Trawl, Camera, box corer	60 pieces/m^2 2000 pieces/m^2
Woodall et al	North Atlantic, Mediterranean, Indian		2014	Deepsea	smedgacorers, boxcores	1.4-30 pieces per 50ml
Castañeda et al	St. Lawrence	2013	2014	Fresh water	sediment samples,	median:52 and mean: 13, 759 m^2
Claessens et al	Belgian Coast		2011	sediment, intertidal	grab, cores	
Claessens et al			2013	sediment	grabs, saline solution	
Näkki et al	Northern Baltic Sea		2017	deep sea sediment	Van Veen Grabs	
Waller et al (Review)	Antarctic and Southern Ocean		2017		Van Veen Grabs, SCUBA	
Katsanevakis et al	Saronikos Gulf (Aegean Sea)		2007	benthic litter, manipulated field experiment	sediment samples	16 items per 100m^2
Martin et al	Irish Continental Shelf	2014 & 2015	2017	Shallow seafloor	box corer	85% Fibres, 15% fragments. 39% subset confirmed polymers. 62 microplastics recovered from 11 stations
Cauwengerghe et al			2013	Deepsea sediment	Cores	5 particles from 4 sample

						locations. 0.5 abundance of 25cm^2 in top 1 cm of sediment
Moskeland et al	Norwegian Continental Shelf		2018	Benthic sediment	van veen grab	average concentration 480 mMp/m^2. Highest concentrations in proximity of Oil and Gas installations, fishing and marine activities in Central North Sea.
Ling et al	South Eastern Australia		2017	Benthic sediment	Van Veen grab	9552 microplastics from 42 sample sites with plastic filaments most common
Barrows et al	Maine coast, US	2014	2020	Benthic sediment	neutson tow and grab samples	Average 5.9 microplastics per L. Neuston tows averaged 213 709 microplastics per km^2. Microfibers were the majority of plastic found. Grab samples collected higher non-fibrous plastics compared to neuston tow.

Table 9 Literature review of benthic video plastic debris studies.

Author	Location	Year of Study	Year of Publication	Study	Method	Results
Pham et al			2013	Underwater seafloor	video, video tows, still photos, trawl	546 litter items; 41% items were plastic and 34% derelict fishing gear
Galgani & Andral	Europe		1998	Deepsea	Video	Video was unsuccessful
Bergmann & Klages	Arctic		2012	Deepsea	Video tow	27 items of debris recorded and 24 of 2878 showed litter
Dufault & Whitehead	Nova Scotia, Canada		1994	Surface	Floating debris	Densities ranged from 0 to 112.8 items km^2. Average densities were 31.6 items km^2 in the Gully area and 11.0 items km^2 outside. Local debris was identified through visible labels
Tekman et al			2017		Photo transects	Zero rich
Mordecai et al	West Coast of Portugal		2011	Submarine Canyons	ROV video and still photos	134 items found from 11 of 16 dives.
Buhl-Mortensen & Buhl-Mortensen	Nordic Sea	2006-2017	2017	Deepsea	video tows	488 litter debris found from 1778 transects (27%). A total of 858

						items of litter were found
Woodall et al	Atlantic and Indian Oceans		2015	seamounts, banks and ridge	ROV	Atlantic Ocean had a total of 56 items found and the Indian Ocean found 31 items.
Lundqvist	Swedish northwest coast	2012	2016	seafloor in shallow (<20m)	Towed video	2868 litter items/km^2
Watters et al	California		2010	Deepsea	submersible vehicle	Density averaged 1.7 items/100 m. 712 debris items found in 52 transects of 112 (32%).

Table 10 Literature review land survey debris studies

Author	Location	Year of Study	Year of Publication	Study	Method	Results
Mathalon & Hill	Halifax harbour, Canada	2012-2013	2014	Intertidal	sediment sample; trowel 3-4 cm deep at low tide	Approx. 20 -80 microplastics/10 g sediment
Viehman et al	North Carolina, USA		2011	Salt marsh intertidal	Surface collection of visible debris (approx. 1.5cm)	14 747 debris items (2849 kg)
Uhrin & Schellinger	North Carolina, USA		2011	Salt marsh intertidal	Blue crab pots and vehicle tires were placed into the marsh environment and checked on weekly.	Blue crab pots and vehicle tires negatively impact marsh grass (*S. alterniflora)*

Podolsky	Maine		1989	Intertidal	high water mark- 100m	301/25kg plastics found. Mean of 20-85kg of macroscopic plastic debris/km of shoreline. Boulder = 68-82kg, beach = 31-25kg. Plastic in salt marshes = 23-39 kg/km. High meadows = 27-21 kg/km. Ledge shores = 5-47 kg/km. Physical characteristics of shoreline habitats impact the accumulation of plastic debris. Rocky and boulders, vegetation in salt marshes = more plastics
Dixon & Cooke	Sandwich Bay, Kent, UK		1977	Intertidal	Visible debris collected at the high water mark	Concluded household products the majority of items found. Wave action caused glass items to break.
Moore et al	California		2001	Intertidal	Beach debris was surveyed and collected	43 sites from August 2- Sept 18, 1998 with 22.9m length transects. 106 million items. Weigh approx 12 metric tons
Brown et al	Tamar Estuary in NE Atlantic		2010	Estuarine Shoreline	strandline survey and underlying 3cm of sediment	952 items from 30 samples of sediment. They found more microplastics compared to

						macroplastics with 65% microplastic total amount. Spatial distribution of plastics due to wind, size and density of plastics
Hidalgo-Ruz & Thiel	Chilean beaches		2013	Citizen science shoreline survey	Quadrat	90% of 39 sampled beaches found small plastic debris. Papudo Beach had 94% small debris were pellets. Aysén region had 169 items M^2 and Bío Bío 165 items M^2. Magallanes had less than 1 item M^2, Los Ríos and El Maule (4 items m2) Easter Island had the highest abundance with 805 items m^2
Storrier et al	Scotland		2007	Beach litter	Litter deposition	45,659 items recorded
Corcoran et al	Kaui's, Hawaii, USA		2009	Beach litter	beach litter degradation	floating debris deposited on shore in a zig-zag pattern. Plastic debris gets deposited along the highwater mark due to tides
Dippo	Western Iceland (North Atlantic Ocean)		2012	Shoreline sediment	high strandline, quadrats	1307 items total
Walker, Grant, Archambault	Halifax, CA		2005	Beach survey	low tide- from high water mark	2129 items. Debris from shipping

					to low water mark	activities was low despite busiest port in Eastern Canada
Thompson et al	Plymouth, UK		2004	Sediment collection	Sediment samples collected from beaches, estuarine, and subtidal	Synthetic polymer fibers were most abundant (23 out of 30 samples) and significantly found in subtidal samples

4.2.1 Canadian Arctic Plastic Research

Liboiron et al (2021) conducted a surface water study to determine the concentration of plastic debris in Frobisher Bay, NU and found an average concentration of 0.018 plastics/m^2. They concluded that this was a lower abundance than the limited studies for surface Arctic waters (Liboiron et al., 2021). Other plastic pollution research conducted in the Canadian Arctic includes: biomonitoring (Avery-Gomm et al., 2012; Bourdages et al., 2020; Morris et al., 2014; Provencher et al., 2010;), surface water (Huntington et al., 2020; Liboiron et al., 2021), sediment samples (Huntington et al., 2020), seafloor (Bergmann et al., 2017; Tekman et al., 2017), and ice (Kanhai et al., 2020; Obbard et al., 2014).

4.2.2 Global Benthic Sediment Research

Benthic debris found in the grab samples for 2016 and 2017 had a lower concentration than other benthic grab plastic literature globally. Moskeland et al. (2018) and Barrows et al. (2017) and Ling et al. (2017) used grab sampling methods for benthic sediment which makes comparison easier. Moskeland et al. (2018) sampled benthic sediment using a grab sampler in the Central North Sea and determined an average concentration of 4900 items per kg. Moskeland et al (2018) used multiple methods to determine efficiency and determined that the $ZnCl_2$:$CaCl_2$ solution did not work efficiently for plastics that have higher densities. They developed the Bauta microplastic-sediment separator (BMSS), and finally a chemical digestion using mixture of NaOH, urea and thiourea. They found that the $ZnCl_2$:$CaCl_2$ solution has a higher concentration than the saline solution, however, it would be underestimating the amount of plastics in the sediment sample as some plastic debris are denser than concentrated saline solution.

Ling et al. (2017) conducted sediment sampling in southeast Australia found an average of 3.4 microplastics/ml of marine sediment. They concluded that filaments were the most common type in the smaller sized sediment classification. In the northwest Pacific, Fisher et al. (2015) found that microplastics were found in the top layer (0-2cm) of sediment but also in the deeper layers. They determined that 75% of debris found were fibers and the remaining 25% were paint chips or unknown pieces. In the St. Lawrence River, from Lake St. Francis to Quebec City, Canada, Castañeda et al. (2014) found mainly microplastics in samples. The median was 52 m^{-2} and the mean was 13, 759 m^{-2} microbeads found in sediment samples. Martin et al. (2017) study on the Irish continental shelf, found an average of 89% recovery of plastics using box coring methods and determined that most debris was found within the first 3cm of benthic sediment.

Overall, the benthic debris found in this thesis showed lower debris abundance than other benthic studies mentioned here.

4.2.3 Benthic Seafloor Video/Photo

Comparing benthic seafloor video/photo studies is challenging due to the different methods and equipment used to collect benthic data (Table 10). The most common debris found in benthic seafloor video/photos are plastic items. Bergmann & Klages (2012) collected seafloor video/photo benthic data in the eastern Fram Strait west of Svalbard in 2002, 2004, 2007, and 2011 using a towed camera for four hours. A total of 2878 photos were analyzed and recorded 27 debris items in 24 images.

Buhl-Mortensen & Buhl-Mortensen (2017) conducted a total of 1778 seafloor video transects in the Norwegian Sea and found 858 debris. They concluded that more debris was found closer to shore rather than offshore. Off the Swedish northwest coast in in Fjällbacka, Koster, and Strömstad, Lundqvist (2016) captured benthic seafloor video footage. They used an underwater camera attached to a sleigh to skim across the seafloor and capture video for macroplastic debris. They found 2868 litter items/km^2 which consisted of 41% plastic, glass/ceramics (25%), metals (24%), natural products which included rope/wood/cardboard (9%), and 1% miscellaneous which included clothing/shoes. They found that debris accumulation increases with depth however, found no significance in their findings.

Tekman et al. (2017) used seafloor imaging to determine the amount of debris in the eastern Fram Strait, between Greenland and Svalbard. They found mostly smaller debris (57%), while 40% was medium sized, and only 4% was classified as large items. They determined that 47% was plastic, 26% glass, 11% rope, 7% metal, 6% fabric, 4% paper/cardboard, pottery, and timber.

Other benthic studies used ROVs which offer high quality seafloor video and precise sample collection (Melli et al., 2017; Mordecai et al., 2011; Pham et al., 2014; Woodal et al., 2015). The results obtained by this method are difficult to compare from the results from this thesis due to the equipment used to collect data. The average debris found in this thesis was lower than the average amounts of debris found in other benthic seafloor video/photo studies.

4.2.4 Intertidal Survey

Beach surveys for plastic debris accumulation are common, however, surveying the intertidal zone for debris is less so.

Mathalon & Hill (2014) collected sediment and mussel samples to analyze for micro and macroplastics in Halifax Harbour, NS. Subsamples of 10g of each sediment sample were used and tested with hydrogen peroxide to remove any organic matter. They found that fibers were the most common debris from the sediment samples. The average concentration was about 20-80 microplastics/10g of sediment. Viehman et al. (2011) conducted an intertidal survey looking for visible debris on North Carolina's coast, USA. They found that plastic was the most common debris found for both small and medium size classifications (0-5cm and 5-50cm). They concluded that the larger debris (>300cm) was predominately fishing gear/equipment. They found that the sites closer to shore had higher concentration of debris with the highest concentration of debris in natural wrack lines. Podolsky (1989) observed at Cross Island, Maine, USA, an average of 20.85kg macroplastics/km of shoreline in this remote, uninhabited study area.

Overall, the abundance of benthic debris found in sediment and in seafloor video/photos are lower than other studies for plastic pollution. The intertidal debris found for this thesis was also lower than other tidal studies. This shows that Frobisher Bay, NU has a low abundance of debris in the intertidal environment.

4.2 Sources of plastics

The three methods used to determine the amount of debris in Frobisher Bay, NU mostly locally-based debris, and almost all close to shore and known human activity. The debris found was accidental and/or unintentional debris that was lost, snagged, or due to a lack of infrastructure for disposal. Mechanical forces such as wind, tides, and currents are potential vectors that push plastic debris from land into Frobisher Bay (Claessens et al., 2013).

The benthic sediment debris is affected by the daily tides and currents which potentially transport debris out of the bay into the Atlantic. Site B-5C-G2 (63.660845, -68.422138, 66.3m depth) had the most plastic debris which contained mostly PVC/gypsum. This station was close to the city of Iqaluit, showing that construction debris from land is a potential source of debris entering Frobisher Bay. The two vials found at station B-5-G3 (63.67359, -68.43049, 56.3m depth) were also recovered close to shore and did not have significant signs of weathering as the wording was still readable. This indicates likely local sources.

The most common morphology of plastic debris found was fragments (22%) in the benthic sediment samples. Threads accounted for (5.5%) and films (3.6%) for the types of plastic debris found. One of the fragments (FB2-2 Rep 1) showed signs of melted debris which shows that burnt debris from the local landfill could be potentially a point source. However, with only one burnt debris found representing (1.8%) of the total sample collection does not show a strong potential of burnt debris entering Frobisher Bay from the local landfill which has previously been affected by accidental fires (Zahara, 2015). Threads come from fishing gear, but these accounted for only 5.5% of items, which is extremely small compared to other areas with fishing activities (Liboiron et al. 2016).

The benthic seafloor video debris observed in Frobisher Bay were assumed to be mostly from local sources. Station A-5b (63.72559833, - 68.52117333, depth of 8.9 metres), yielded the most plastics and was the closest to human activity. This location is active with ship barges being towed to land, construction area, and fishing and hunting. The majority of plastics found at this site were fishing line which was entangled with kelp and does not easily disperse from the area. This finding, combined with the low number of threads recovered in the benthic samples, indicates that fishing gear may remain more or less in place and intact once it is lost to the environment. This hypothesis is strengthened as the NRCI report (2016) records less fishing and hunting further out in Frobisher Bay. This site also had a large intact bag with colour which shows it would be a local debris that had not undergone degradation. It is highly likely the bag originated on the shore. The winds and tides could be potentially transporting the debris away from Iqaluit and into Frobisher Bay, particularly for lighter film (bag) plastics.

The debris found in the intertidal survey are macroplastics that have not been impacted by mechanical forces and have not been transported out into Frobisher Bay. They are very likely local. Most of the debris found related to construction debris which is represented by this location being impacted by shipping barges being towed into Iqaluit and the construction site nearby. Ship barges are towed to land from anchored ships in the Bay. Some of the debris that was found included food packaging which still had colour which shows that the debris would be from local sources as it was not weathered long causing discolouration. During low tide, Foraging for Arctic soft-shelled clams, *Mya truncata*, is practiced as this location. During high tide, fishing/hunting activity increases.

4.4 Relationship to specific human activities

Northern communities are affected by pollution from plastics being dispersed by water, ice, and the atmosphere from a global context. Iqaluit, NU is a northern community being affected by both local and non-local plastic debris sources, though most sources found here were local. The debris found in 2016 and 2017 related to human activity which included fishing, construction, and researcher contamination/waste. The debris was recorded close to areas of higher human activity rather than further out in Frobisher Bay where less human activity occurs. The two glass vials were found close to shore where higher human activity occurs. These two vials, New England Nuclear, were likely local debris from hospital waste, determined by the New England Nuclear label which is a company that makes radioactive chemicals for research and radioactive pharmaceuticals for medical diagnosis (Kendall et al., 1981) in additional there is no nuclear energy in Iqaluit (Qulliq Energy Corporation, n.d.).

The landfill, which has been on fire in recent years, is potentially a point source of debris entering Frobisher Bay. However, it was hypothesised that higher amounts of burnt debris would be found in Frobisher Bay. Only one burnt debris was found in the 2016 samples which shows that the fire in 2014 at the Iqaluit landfill is not a significant source of debris entering Frobisher Bay during the collection in 2016 and 2017. The wind patterns for Iqaluit are predominantly northwest and southeast (Hudson et al., 2001). The northwest winds occur longer and therefore would affect landfill debris by transporting from land out into Frobisher Bay. The southeast winds occur for less time, however, these winds would affect debris that can be transported by wind and potentially towards Iqaluit. The southeast winds from the landfill would affect benthic samples further out in Frobisher Bay and would not impact the debris in the intertidal zone.

4.5 Considerations for Future Research in Northern Canada

A consideration for further research could include sampling along the Labrador current as the research vessel, MV *Nuliajuk*, makes it trip from Newfoundland to Nunavut. The MV *Nuliajuk* often docks in Newfoundland during the winter months and then the boat crew brings it back to Iqaluit, NU in the late spring/early summer for work. I recommend that during this transition that plastic pollution research is conducted. This would be helpful to determine the amounts of debris throughout the Labrador current and extending research on plastics into areas more likely to have long-range transport of plastics.

Research waste is also a potential source of non-local debris entering the northern environment. The MV *Nuliajuk* is painted white and blue, there were 53 blue paint chips found in the benthic grab samples are likely from the research vessel via scraping the side of the boat with equipment and potentially paint disintegrating and entering the natural environment. This occurs when equipment unintentionally gets lost, snagged, or damaged during sample collection and is not retrieved. Due to this, the seafloor video collection for this thesis was not towed to eliminate the potential for the boat propellor to accidently cut the camera reel. Going forward, research needs to account for this unintentional waste during any research collection in the North.

Field observations noted that there was a lack of waste disposal on the boat deck and would be recommended to have a designated garbage can and a cigarette butt receptacle. Infrastructure issues has the potential to allow debris to enter the environment. This is noted from the current landfill in Iqaluit, NU that is open, unlined, and on the coastline of Frobisher Bay which has been on fire on several occasions (Zahara, 2015). Only one debris found in the benthic grab samples showed signs of burnt edges which shows this debris could have potentially from the landfill during when it was on fire.

As more development occurs in remote areas, plastic pollution monitoring is important for the understanding health of the environment, wildlife, and human health. Conducting research in any location requires ethics to ensure good relations are established between the researcher(s) and the community the research is being collected. All research needs to be done ethically and equitably respecting research permits, local knowledge, and community collaboration during the entire research project from proposals to rights to publish.

4.6 Biomonitoring Workshop for Nunavut Research Institute

After acquiring research permits and government collaboration for this thesis, I connected with the Nunavut Research Institute and asked if they would be interested in collaborating with this thesis and if they would be interested in doing plastic pollution biomonitoring workshop. This relationship resulted in having the second-year students at the NRI participate as research assistants for the intertidal survey for this thesis. In return, they were interested in having a biomonitoring workshop for plastics in local fish. This biomonitoring workshop included 15 arctic cod and 4 Atlantic cod from Newfoundland that were brought from St. John's as a which was intended for food and science. However, the cooler with these cod was lost during my connecting flight and by the time it reached Iqaluit, NU, they were not fit for human consumption. The cod were still used for the biomonitoring workshop and fortunately the students were willing to take the cod home for their dogs to eat so it was not wasted. A general presentation was given to about the importance of plastic pollution and the importance of biomonitoring local food for the health of the entire ecosystem including humans. The biomonitoring workshop resulted in zero microplastics in the 15 arctic char and in the four Atlantic cod. This is presented here to show what community involvement during research can look like, including sharing skills.

During the workshop, I learned a lot from these students and how they conducted science. Students with young children had to pick them up from school and brought them back to the workshop and had them participate and engage with the fish looking for microplastics as well. This showed me that science does not need to include white lab coats and only for scientists.

During the intertidal zone survey for macroplastics, the students followed a protocol, conducted quadrat analysis for debris, counted and documented debris, and collected and bagged debris found. This was a cold day in October, 2017 and the students were great to work with during this part of the thesis project. After the survey was conducted, I offered the students if they would be interested to be included as co-authors and or acknowledged for their work. This was part of my methods to include all people who were part of this thesis.

4.7 Doing Science in the North

Working in northern Canada requires a making back-up plans when flights, luggage, equipment do not get to the destination. The MV *Nuliajuk*, was ahead of schedule and required the flights to be changed to accommodate getting to Iqaluit earlier. What was quickly realized, was to not get a round trip when working in northern Canada as changes to the research trip happen and researchers need to be ready to accommodate these last-minute changes. Another factor to consider was to bring essential equipment and personal care products in a carry-on. Unfortunately, the luggage was lost during flight changes and some equipment did not make part of the research trip. Being adaptable and flexible is important when working in the North.

5.0 Conclusion

Plastic pollution is a global issue affecting the natural environment and potentially affecting human health. Anthropogenic debris can be found all across the world including remote areas. The coastal community, Iqaluit, Nunavut is a point source of debris entering Frobisher Bay. This thesis was formed using existing research samples from Frobisher Bay from previous 2016 thesis work and continue in 2017 with dedicated sample collection with plastic pollution control methods in place. Iqaluit, Nunavut has an open landfill on the coast of Frobisher Bay which has previously been on fire throughout the years. During this thesis, benthic grab sediment samples were examined for microplastics from Frobisher Bay, sampling in areas of high human activity such as fishing and hunting. Macroplastic sampling was conducted with an underwater camera system that was deployed at the same sites for benthic grab samples. Finally, an intertidal survey was conducted in the area where ship barges are hauled to shore during low tide. The concentrations for the three different methods conducted during this thesis found 0.002 objects/ml in the benthic grab samples, 0.055 objects/minute for the seafloor video for macroplastic, and 0.379 objects/m^2 intertidal survey. Plastic debris found in the benthic zone are related to fishing activities (fishing line) and from land (limited burnt material from the landfill and construction materials). The main sources of the intertidal survey plastics found were from land-based activities including food wrappers and construction material. A field observation recommendation is to provide cigarette disposal units on marine vessels. The invitation to work with the students and teachers at the Nunavut Research Institute to conduct a biomonitoring workshop on cod brought from St. John's Newfoundland provided a knowledge sharing and collaborative experience. A community event was held to present the findings found in this study in September 2018. Overall, benthic plastic pollution in Frobisher bay and intertidal survey found low concentrations of plastic debris compared to other debris studies. This baseline study of debris found in the benthic zone and intertidal zone will provide Iqaluit, Nunavut data on the natural environment prior to any increased coastal development which may potentially lead to more plastic debris entering Frobisher Bay. The open landfill in Iqaluit will continue to pose a potential source of plastics entering the Bay and innovative waste management strategies will be required.

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Appendices

Appendix 1. Scientific Research License 2017

Nunavummi Qaujisaqtulirijikkut / Nunavut Research Institute

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SCIENTIFIC RESEARCH LICENSE

LICENSE # 01 016 17R-M

ISSUED TO: Linda Ham
Canada Nunavut Geoscience Office
PO Box 2319
Iqaluit, Nunavut X0A 0H0 Canada

TEAM MEMBERS: T. Tremblay, J. Kennedy, A. Aitken, C. Campbell, R. Bennett, A. Robertson, V. Barrie, T. Bell, E. Edinger, E. Herder, B. Misiuk, K. Regular, K. Zammit, R. Deering, H. Bradshaw

AFFILIATION: Natural Resources Canada

TITLE: Seabed Mapping of Frobisher Bay to Support Infrastructure Development & Natural Hazard Assessment

OBJECTIVES OF RESEARCH:
Frobisher Bay is a large inlet with extremely high tides and complex bathymetry, with Iqaluit, Nunavut's capital city, located near its innermost end. Therefore Frobisher Bay is an extremely important waterway for Nunavut, involving transportation, infrastructure development both on land and under water. Furthermore, resource development, both on land and under water, has the potential to affect the natural system of the bay. New marine geoscience information is required to guide sustainable development by understanding marine geohazards such as submarine landslides, natural petroleum seeps, iceberg scour, nearshore ice scour, tidal currents, and wave exposure.

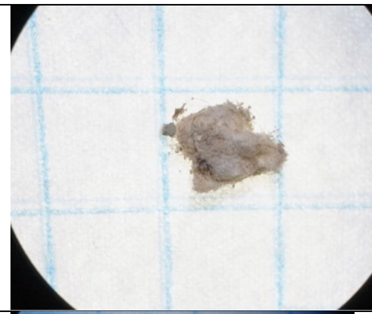
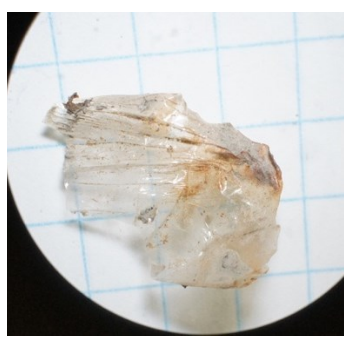
TERMS & CONDITIONS:
The holder of this licence will be bound by the terms and conditions from the Nunavut Impact Revew Board Screening Decision Report and per the Department of Culture & Heritage Archaeological Sites Terms and conditions.

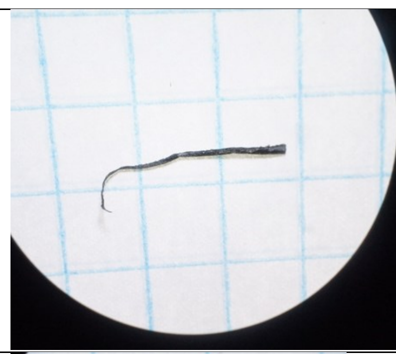
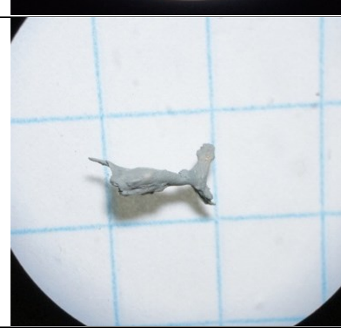
DATA COLLECTION IN NU:
DATES: September 01, 2017-December 31, 2017
LOCATION: Frobisher Bay

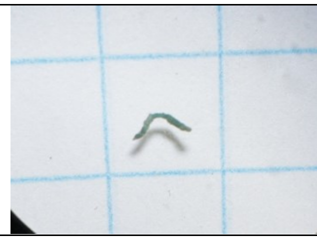
Scientific Research License 01 016 17R-M expires on December 31, 2017
Issued at Iqaluit, NU on September 25, 2017

Mary Ellen Thomas
Science Advisor

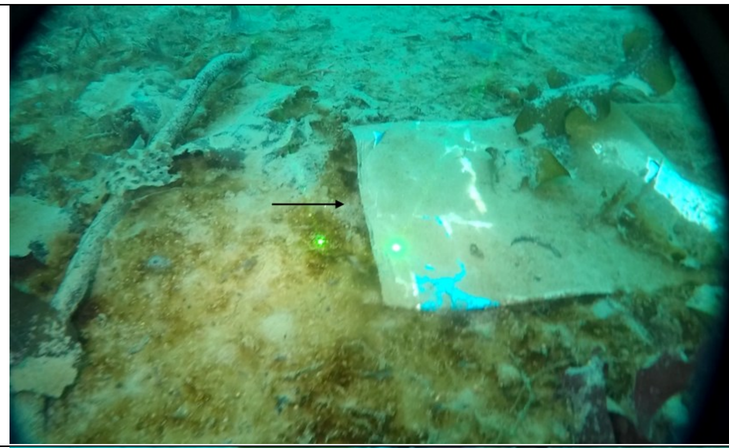
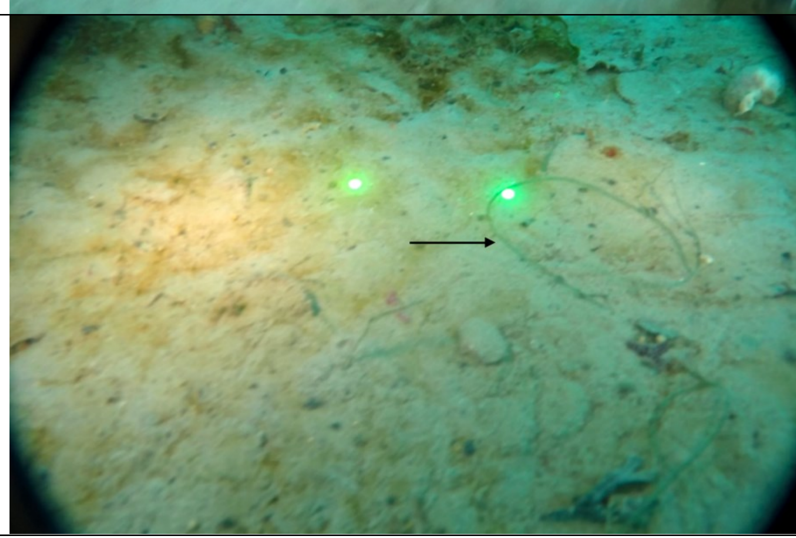
Appendix 2. Benthic debris photos found in grab samples in Frobisher Bay, Iqaluit, NU in 2016 and 2017

A-5B-G2 (2016): PVC and gypsum, white fragment with frayed ends	
A-5B-3 (2016): non-plastic; carbon steel; red/black, pitted/discoloured	
B-5C-G (2016): plastic; PE, white with blue	
A-25-G4 (2016): plastic, PE, clear film with slight discolouration	

A-25-G4 (2016): plastic, PE, clear thread with frayed ends and discolouration	
A-28-G1 (2016): PE, black fragment with no signs of erosion	
B-5 (2016): non-plastic; glass with readable label; New England Nuclear NEC-086s NaHC^{14}O 1.0mL Sterile H2OpH9.5 L01 No. 670-079 10.0 µCi 100.0 µgms	
FB2-2 Rep 1 (2016): plastic, black fragment with frayed and melted ends	
FB2-2 Rep 3 (2016): plastic, PAH, grey/blue fragment	

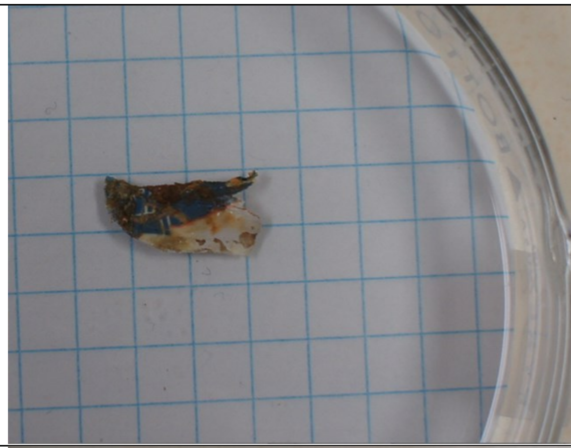
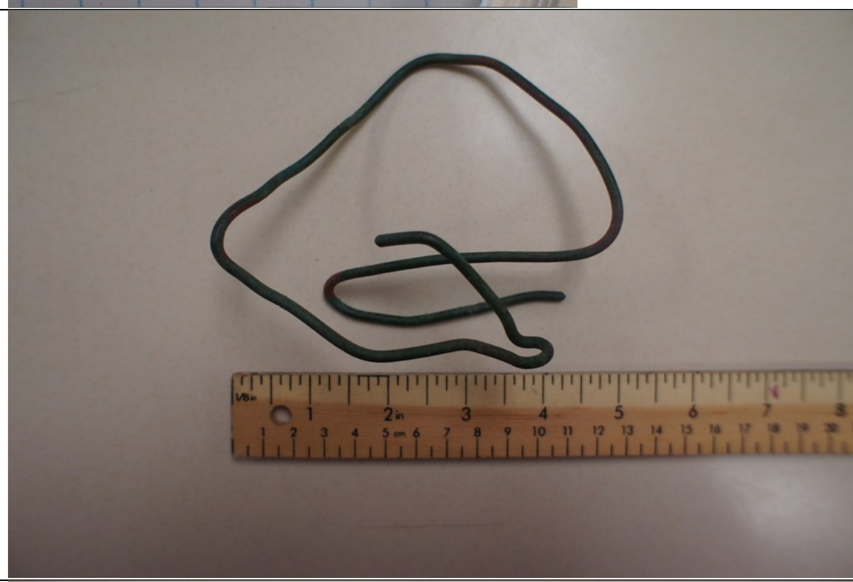
IFB_2 (2017): plastic, PE, green fragment	

Appendix 3. Benthic Plastic Debris found in Frobisher Bay, Iqaluit, NU 2016. Laser pointers have a distance of 5cm.

A-5B (2016): plastic debris, bag	
A-5B (2016): plastic debris, fishing line	
A-5B (2016): plastic debris, fishing line	

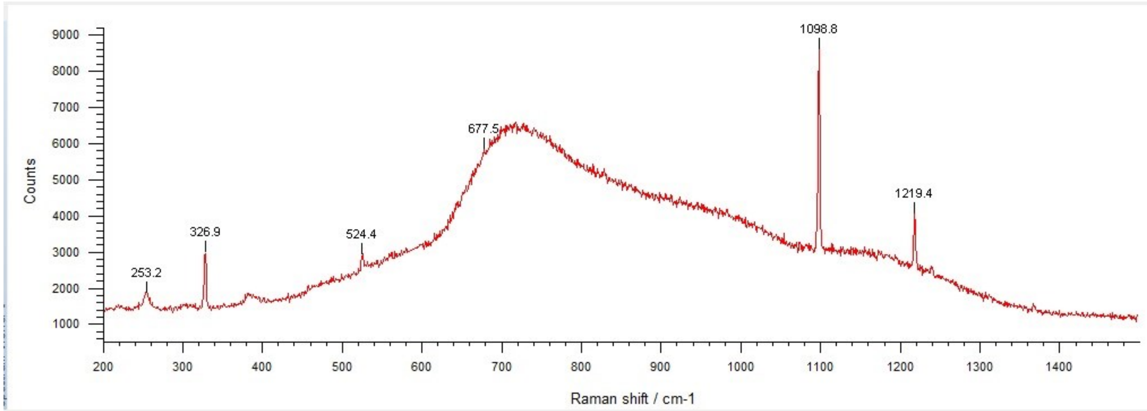
Appendix 4. Intertidal Survey Macrodebris in Iqaluit, NU 2017

Transect 3 Quadrat 20 (2017): intertidal macroplastic, black and white rope with frayed ends and some discolouration	
Transect 1 Quadrat 2 (2017): intertidal debris, metal with signs of rust	
Transect 1 Quadrat 2 (2017): intertidal debris, metal with signs of rust	

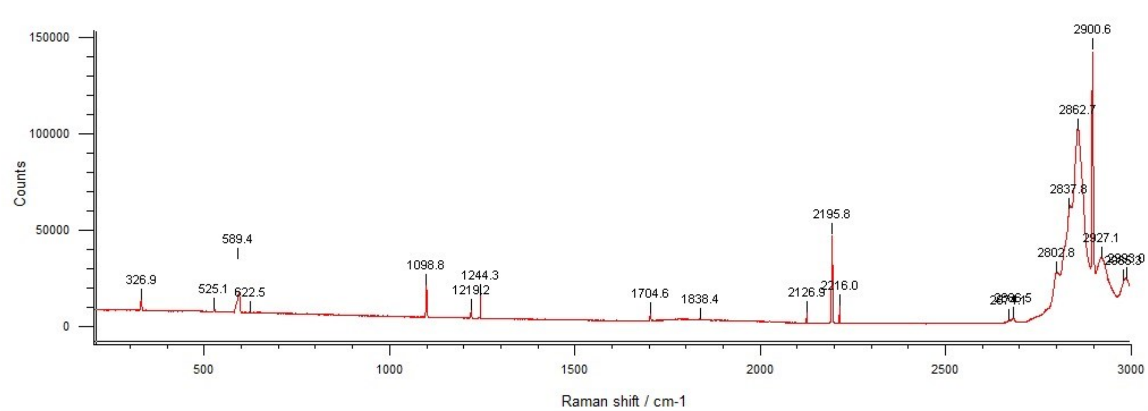
Transect 3 Quadrat 23 (2017): intertidal plastic debris, blue and white film with signs of discolouration and frayed ends	
Transect 1 Quadrat 3 (2017): intertidal debris, green metal wire with signs of discolouration	
Transect 1 Quadrat 6 (2017): intertidal macroplastic debris, blue film tarp with signs of weathering	

Transect 3 Quadrat 21 (2017): intertidal macroplastic debris, wax paper with discolouration	
Transect 1 Quadrat 4 (2017): intertidal macroplastic debris, yellow foam with duct tape attached with minor signs of weathering	
Transect 3 Quadrat 30 (2017): intertidal macroplastic, black garbage bag with signs of discolouration	

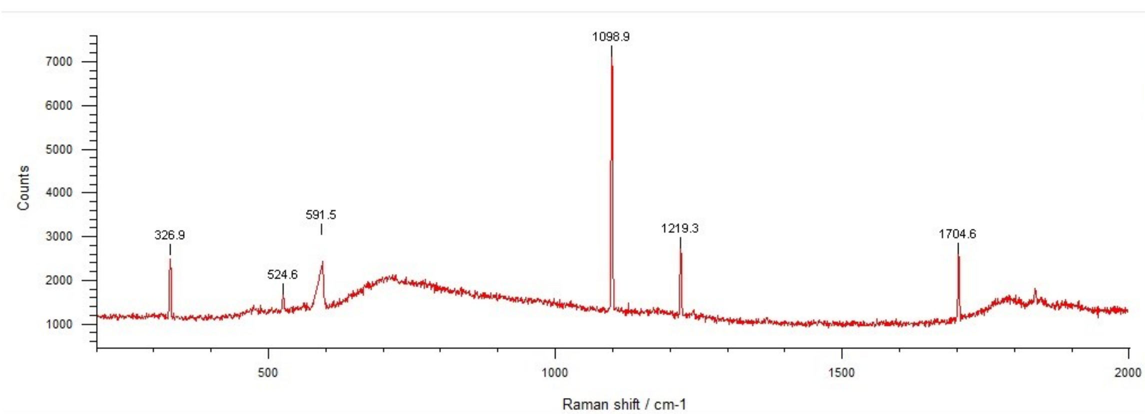
Appendix 5 Raman Spectroscopy Strata



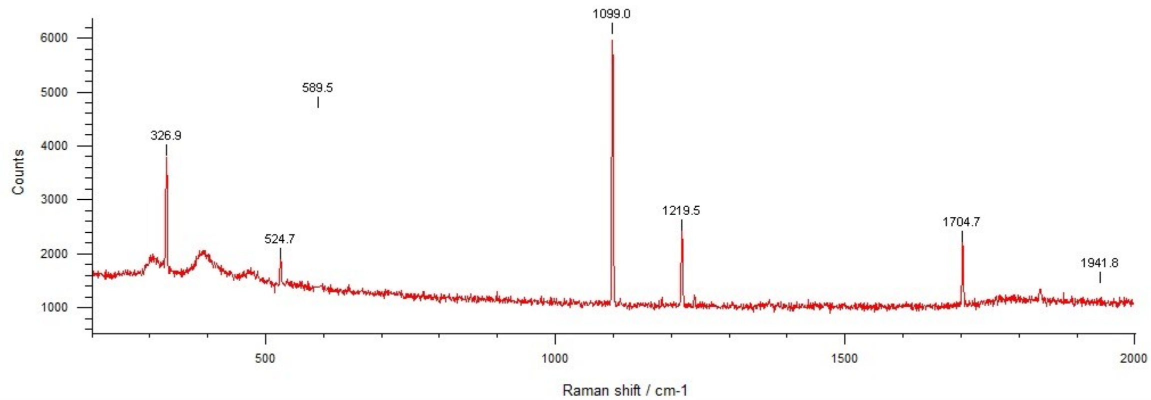
A-5B-G4: Rust



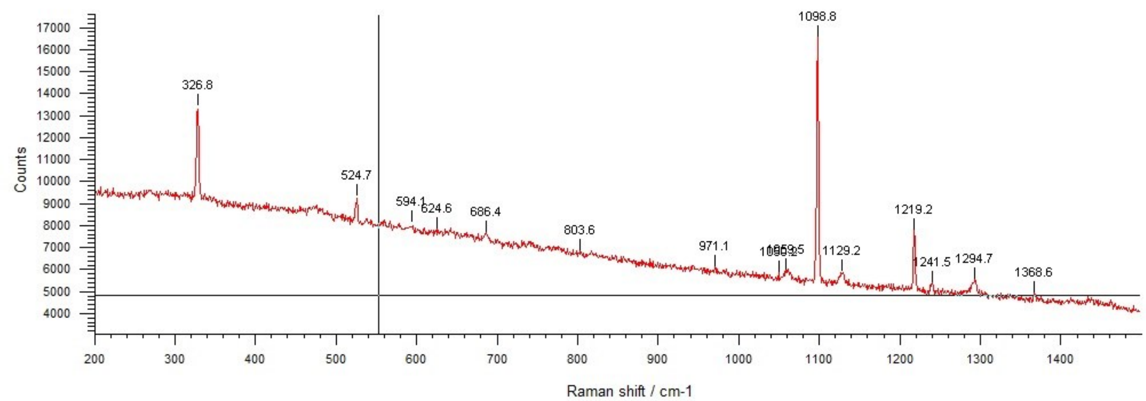
A-25-G4: PE: plastic thread



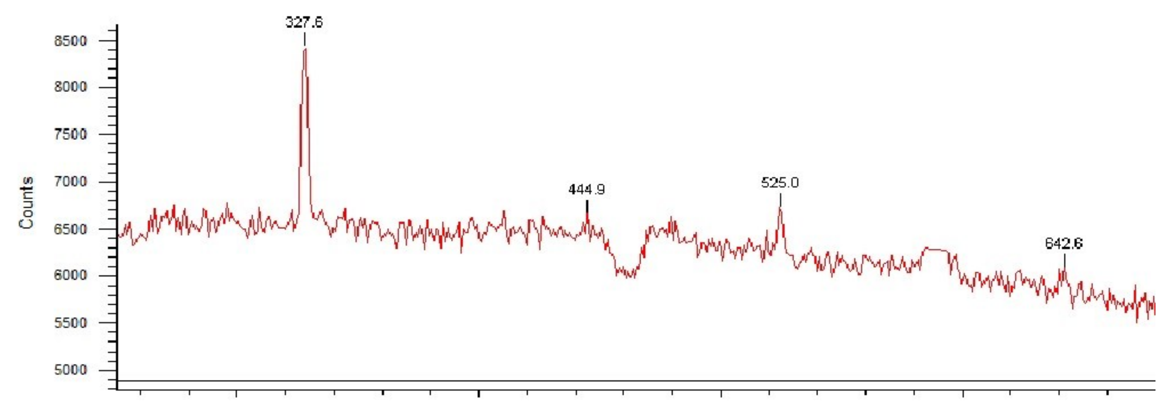
A-28-G1



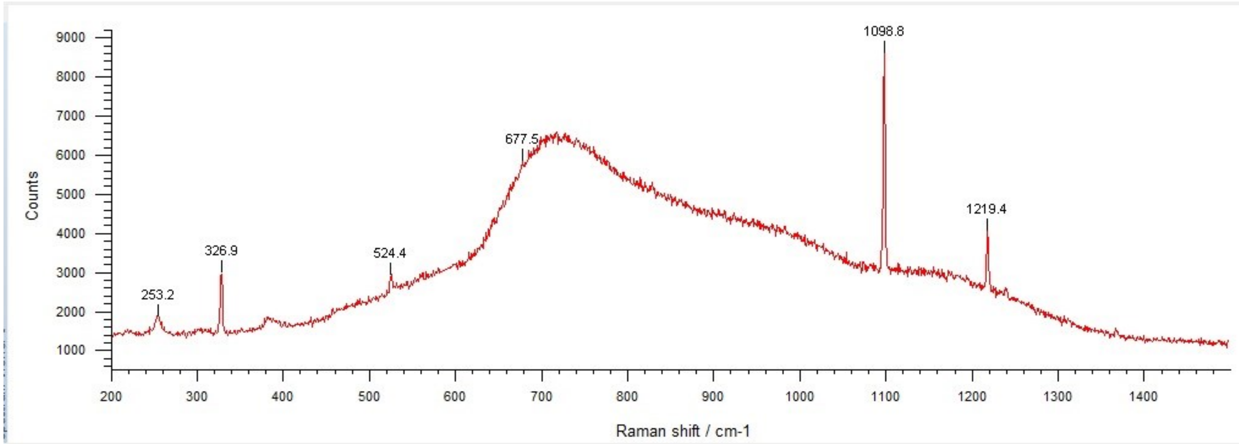
A-28-G1: rust



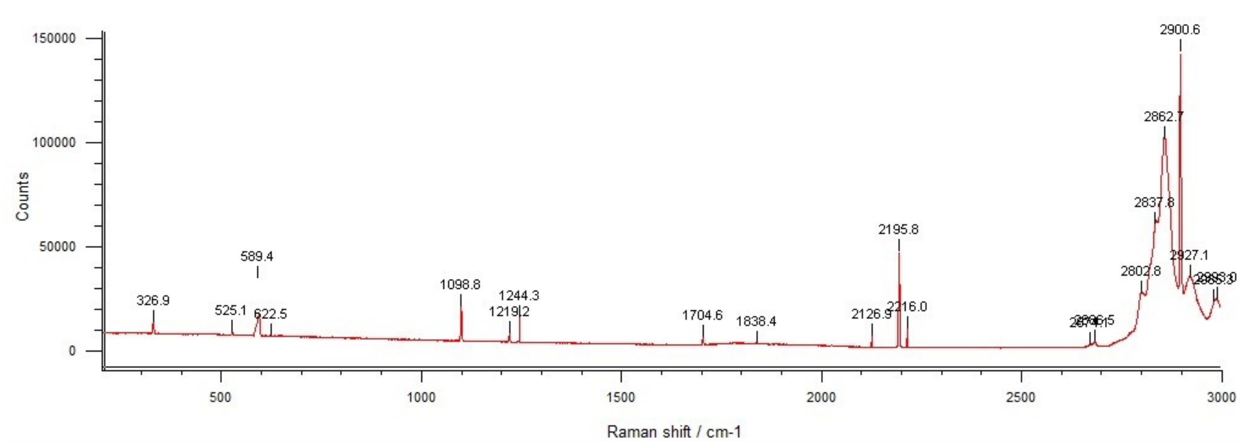
A-28-G1



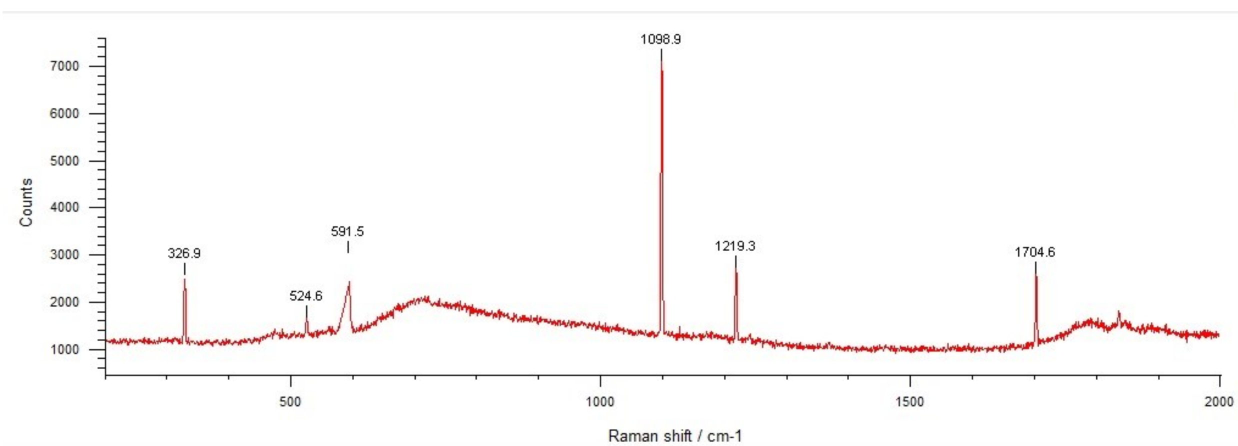
B-5C-G1



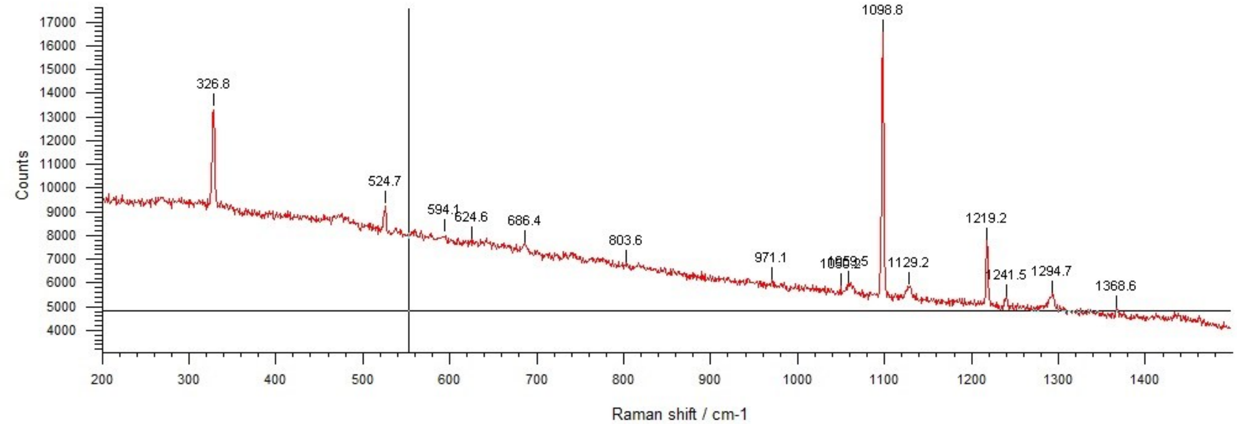
Raman Spectra for Rust



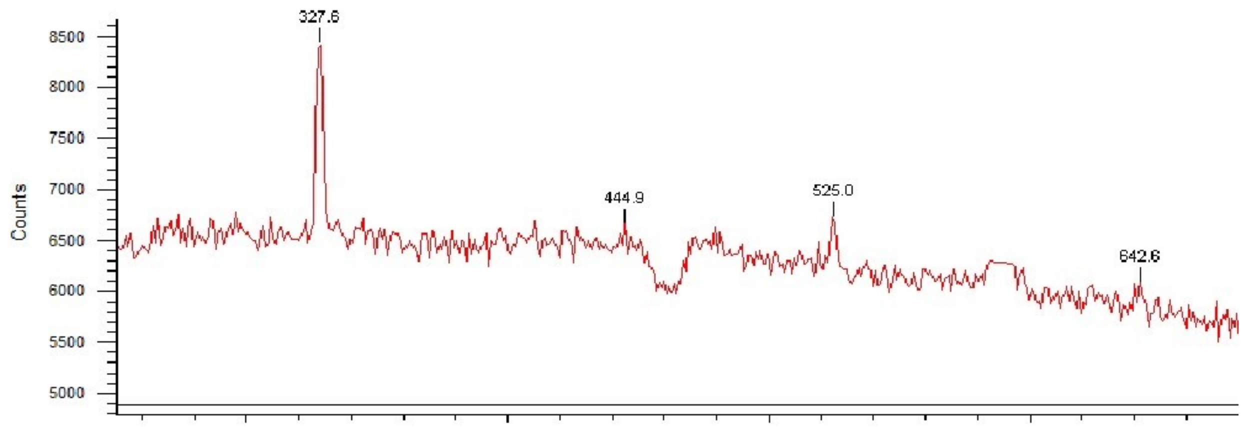
A-25-G4; Plastic Film; PC



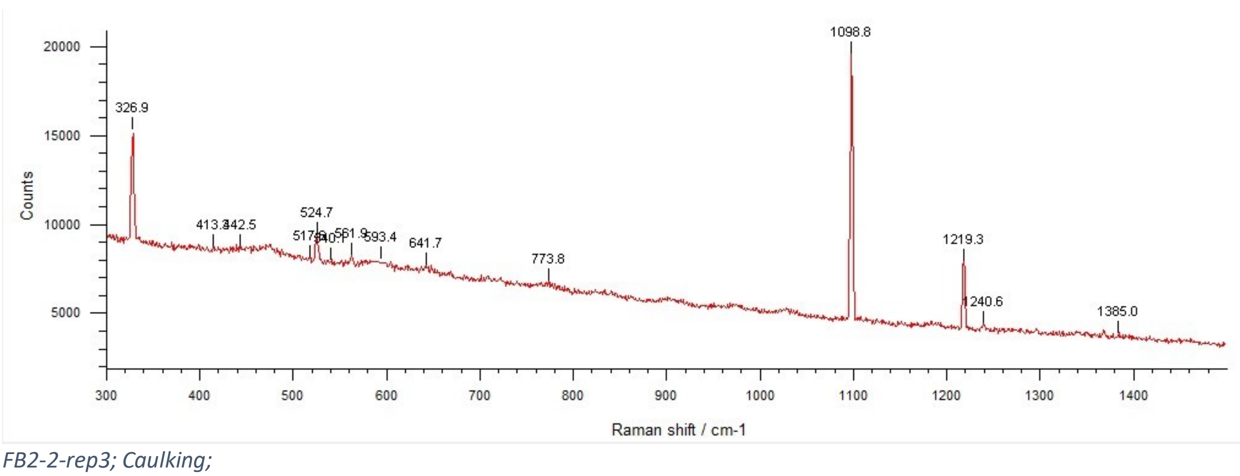
A-25-G4; Plastic Thread; PE



B-5c-G2; Plastic Thread; PE



B-5C-G3; Paper;



FB2-2-rep3; Caulking;

Appendix 6. Metadata from Grab Samples from Research Collected in 2016

Station	Replicate	DateSampled	LatitudeDD	LongitudeDD	WaterDepth	Vessel	StudyArea	GrabSampler
B-5a	G1	13/08/2015			50	22' Fishing Boat	Long Term Ecology	
B-5d	G1	13/08/2015			45	22' Fishing Boat	Long Term Ecology	
B-5g	G2	13/08/2015			83	22' Fishing Boat	Long Term Ecology	
A-26	G1	13/08/2015			40	22' Fishing Boat	Long Term Ecology	
A-25	G1	2016-10-10	63.7226917	-68.51627	28.5	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-25	G2	2016-10-10	63.722415	-68.51629667	27.6	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-25	G4	2016-10-10	63.7226167	-68.51646667	27.6	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-26	G2	2016-10-10	63.712755	-68.50312167	35.2	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-26	G3	2016-10-10	63.712595	-68.503075	35.9	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-26	G4	2016-10-10	63.7123133	-68.50258833	37.8	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-27	G1	2016-10-10	63.6968817	-68.48922667	33.1	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-27	G2	2016-10-10	63.6970833	-68.48894333	30.1	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-27	G3	2016-10-10	63.6969983	-68.489645	???	M.V. Nulialjuk	Long Term Ecology	Van Veen

A-28	G1	2016-10-10	63.7099633	-68.52109167	11.5	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-28	G4	2016-10-10	63.7099883	-68.52139667	10.3	M.V. Nulialjuk	Long Term Ecology	Van Veen
A-28	G5	2016-10-10	63.7101217	-68.52178167	10.2	M.V. Nulialjuk	Long Term Ecology	Petite Ponar
A-5b	G2	2016-10-10	63.725545	-68.520935	8.5	M.V. Nulialjuk	Long Term Ecology	Petite Ponar
A-5b	G3	2016-10-10	63.7255383	-68.52046	10.5	M.V. Nulialjuk	Long Term Ecology	Petite Ponar
A-5b	G4	2016-10-10	63.7257317	-68.52191833	15.4	M.V. Nulialjuk	Long Term Ecology	Petite Ponar
B-5	G1	2016-11-10	63.6729233	-68.42937667	57	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5	G2	2016-11-10	63.6735067	-68.428265	58.6	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5	G3	2016-11-10	63.673585	-68.43048667	56.3	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5a	G7	10/14/2016	63.6683367	-68.43358833	69.2	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5a	G8	10/14/2016	63.66823	-68.43384667	68.1	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5a	G9	10/14/2016	63.6686967	-68.43357333	70	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5c	G1	2016-11-10	63.661055	-68.42160333	77.2	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5c	G2	2016-11-10	63.660845	-68.42213833	66.3	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5c	G4	2016-11-10	63.6610167	-68.42195333	74.1	M.V. Nulialjuk	Long Term Ecology	Van Veen

B-5d	G1	2016-11-10	63.6775933	-68.420925	25	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5d	G2	2016-11-10	63.6780483	-68.42221667	27	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5d	G3	2016-11-10	63.6778517	-68.42123833	23.9	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5e	G1	2016-11-10	63.6756683	-68.43029667	52.3	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5e	G2	2016-11-10	63.6757233	-68.43128167	53.7	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5e	G3	2016-11-10	63.6751917	-68.42991333	55.4	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5f	G6	2016-11-10	63.663945	-68.41960833	90.1	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5f	G7	2016-11-10	63.6641283	-68.42056	88.2	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5f	G8	2016-11-10	63.6642383	-68.41944	90.2	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5f	G9	2016-11-10	63.6639917	-68.41975333	89.9	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5g	G1	2016-11-10	63.662085	-68.41443333	93.8	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5g	G2	2016-11-10	63.662085	-68.414425	92.8	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5g	G3	2016-11-10	63.6627233	-68.41404	86.1	M.V. Nulialjuk	Long Term Ecology	Van Veen
B-5g	G4	2016-11-10	63.66222	-68.41397833	90.8	M.V. Nulialjuk	Long Term Ecology	Van Veen
FB2-1(5g)	Rep1	16/07/2016	63.6635833	-68.42238333	80	CCGS Amundsen	Long Term Ecology	Box Core

FB2-1(5g)	Rep2	16/07/2016	63.6635	-68.422	80	CCGS Amundsen	Long Term Ecology	Box Core
FB2-1(5g)	Rep3	16/07/2016	63.6635	-68.42166667	81	CCGS Amundsen	Long Term Ecology	Box Core
FB2-2(5d)	Rep1	16/07/2016	63.6752333	-68.43035	63	CCGS Amundsen	Long Term Ecology	Box Core
FB2-2(5d)	Rep2	16/07/2016	63.6752833	-68.43046667	62	CCGS Amundsen	Long Term Ecology	Box Core
FB2-2(5d)	Rep3	16/07/2016	63.6752167	-68.43048333	62	CCGS Amundsen	Long Term Ecology	Box Core
FB2-1(5g)	Rep3	15/07/2017	63.66337	-68.41868	94	CCGS Amundsen	Long Term Ecology	Box Core
FB2-2(5d)	Rep3	15/07/2017	63.67438	-68.42207	31	CCGS Amundsen	Long Term Ecology	Box Core

Appendix 7 Metadata for Benthic Seafloor Video from 2016 in Iqaluit, Nunavut

Station	DateSampled	Start_LatDD	Start_LongDD	End_LatDD	End_LongDD	Start_WaterDepth	End_WaterDepth	Start_Time	End_Time	Vessel	Study Area	VideoType
A-25	2016-10-10	63.7230483	63.51615667	-63.722875	-68.5164183	29.7	28.8	10:56	11:02	M.V. Nuliajuk	Long Term Ecology	High and Low
A-26	2016-10-10	63.7131283	63.50329167	-63.712968	-68.5031333	35.2	33.1	12:31	12:36	M.V. Nuliajuk	Long Term Ecology	High and Low
A-27	2016-10-10	63.6967367	63.48862	-63.696635	-68.4873667	28.5	24.8	21:21	21:25	M.V. Nuliajuk	Long Term Ecology	High and Low
A-28	2016-10-10	63.7097017	63.52165167	-63.709697	-68.5221183	7.8	6.9	14:17	14:22	M.V. Nuliajuk	Long Term Ecology	High and Low
A-5b	2016-10-10	63.7255983	63.52166	-63.725715	-68.5211733	7.6	10.1	17:39	17:43	M.V. Nuliajuk	Long Term Ecology	High and Low
B-5	2016-11-10	63.67337	63.42974833	-63.673565	-68.4294033	57.2	57.5	12:38	12:44	M.V. Nuliajuk	Long Term Ecology	High and Low
B-5a	2016-11-10	63.668695	63.43431	-63.668485	-68.4340183	63.2	63.2	14:00	14:04	M.V. Nuliajuk	Long Term Ecology	High and Low
B-5c	2016-11-10	63.6612	63.422565	-63.6614	-68.4232667	68.7	59.6	17:19	17:23	M.V. Nuliajuk	Long Term Ecology	Low
B-5d	2016-11-10	63.6776517	63.421225	-63.677837	-68.4218517	26.5	26.2	11:44	11:49	M.V. Nuliajuk	Long Term Ecology	High and Low
B-5e	2016-11-10	63.675595	63.43189667	-63.6	-68.4324783	54.7	55.5	11:03	11:07	M.V. Nuliajuk	Long Term	High and Low

				75748							Ecology	
B-5f	2016-11-10	63.6643817	63.41925833	-63.664665	-68.419425	88.5	88.8	14:49	14:53	M.V. Nulialjuk	Long Term Ecology	High and Low
B-5g	2016-11-10	63.6618033	63.41491167	-63.66201	-68.4142967	98.8	94.2	15:06	15:11	M.V. Nulialjuk	Long Term Ecology	High and Low
A-IF-1	2016-10-10	63.7146133	63.50907333	-63.714628	-68.5092467	16	17.4	11:49	11:53	M.V. Nulialjuk	Near Long Term Ecology	High and Low
A-IF-2	2016-10-10	63.7040767	63.53696833	-63.704128	-68.5357767	24.7	19.7	18:36	18:40	M.V. Nulialjuk	Near Long Term Ecology	High and Low
A-IF-18	2016-10-10	63.70363	63.491465	-63.703848	-68.490175	29.4	36.4	20:35	20:39	M.V. Nulialjuk	Near Long Term Ecology	High and Low
A-IF-19	14/10/2016	63.6742517	63.50374667	-63.674255	-68.50315	37.8	41.9	13:17	13:21	M.V. Nulialjuk	Near Long Term Ecology	High and Low
A-IF-20	2016-10-10	63.7067817	63.52143	-63.706852	-68.5219317	14.8	13.9	14:57	15:01	M.V. Nulialjuk	Near Long Term Ecology	High and Low
A-IF-21	14/10/2016	63.6695333	63.50147667	-63.669587	-68.5003467	59.4	62.3	13:59	14:03	M.V. Nulialjuk	Near Long Term Ecology	High and Low
A-IF-22	2016-11-10	63.6655617	63.50312333	-63.665512	-68.503085	56.6	57.3	20:26	20:30	M.V. Nulialjuk	Near Long Term Ecology	High and Low

A-IF-61	2016-10-10	63.71879	63.47287	-63.718708	-68.4723817	23.8	23.1	19:50	19:54	M.V. Nuliajuk	Near Long Term Ecology	High and Low
A-IF-62	2016-10-10	63.711025	63.51019333	-63.710847	-68.510035	12.7	12.3	13:22	13:25	M.V. Nuliajuk	Near Long Term Ecology	High and Low
A-IF-63	14/10/2016	63.6809483	63.47774167	-63.681152	-68.4772383	84.6	78.1	11:55	12:00	M.V. Nuliajuk	Near Long Term Ecology	High and Low
A-IF-68	2016-11-10	63.6811917	63.48194167	-63.68119	-68.4819183	74.6	73.9	21:13	21:17	M.V. Nuliajuk	Near Long Term Ecology	High and Low
A-IF-69	14/10/2016	63.6803933	63.49602333	-63.680262	-68.49586	57.6	57.8	12:38	12:42	M.V. Nuliajuk	Near Long Term Ecology	High and Low
A-IF-70	2016-10-10	63.7046033	63.53344167	-63.704707	-68.5334583	9.7	11.2	16:45	16:49	M.V. Nuliajuk	Near Long Term Ecology	High and Low
B-IF-24	14/10/2016	63.6538167	63.487395	-63.653523	-68.4882267	85.2	72.9	17:24	17:28	M.V. Nuliajuk	Near Long Term Ecology	High and Low
B-IF-33	13/10/2016					76.8	70.8	20:31	20:35	M.V. Nuliajuk	Near Long Term Ecology	
B-IF-64	14/10/2016	63.66602	63.465515	-63.666135	-68.4501767	84.2	97.6	19:26	19:30	M.V. Nuliajuk	Near Long Term Ecology	High and Low

B-IF-66	14/10/2016	63.6553167	63.49086833	-63.65529	-68.49059	88.1	90.2	15:20	15:24	M.V. Nuliajuk	Near Long Term Ecology	High and Low
B-IF-72	2016-11-10	63.6513417	63.45184	-63.65150 8	-68.4523833	76.7	82.4	18:59	19:03	M.V. Nuliajuk	Near Long Term Ecology	High and Low
B-IF-73	2016-11-10	63.654035	63.49715167	-63.654212	-68.4973817	51.2	50.3	19:45	19:51	M.V. Nuliajuk	Near Long Term Ecology	High and Low
B-IF-74	14/10/2016	63.655215	63.453075	-63.65504	-68.454125	93.1	98.9	18:31	18:35	M.V. Nuliajuk	Near Long Term Ecology	High and Low